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Assessment of Hazardous Waste Practices in the Petroleum Refining Industry

Jacobs Engineering Co, Pasadena, Calif

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ASSESSMENT OF HAZARDOUS WASTE PRACTICES IN THE PETROLEUM REFINING INDUSTRY

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This report is a comprehensive review of hazardous waste generation and management practices within the
petroleum refining industry. Nearly 625,000 metric tons (dry weight) of wastes were generated in 1974 by 247 refineries
with a processing capacity of 14.2 million barrels per day. Waste streams emanating from individual refining process
sources are characterized and described in detail. Following site visits and waste stream sampling at a representative
group of sixteen refineries, a laboratory program of chemical analysis was carried out to identify potentially hazardous
constituents of refinery wastes. Concentration levels of these constituents were measured, and hazardous wastes defined
as those with any constituent with a concentration exceeding the average level in the natural soil environment. Oil is the
principal hazardous substance in refinery wastes, representing approximately 110,000 metric tons per year. Metal con-
stituents amount to 250 metric tons, fluoride to 812 metric tons, and phenol, cyanide, and benz-A-pyrene collectively to
6 metric tons. More than half of refinery wastes are removed by private contractors to ultimate disposal in offsite land-
fills or lagoons, however projections indicate a dramatic shift toward onsite disposal, particularly by landspreading and
landfilling. Also anticipated is considerable waste reduction resulting from increased recycling, material reclamation,
and product recovery. The cost to industry for waste treatment/disposal using three levels of technology varies from
$1.80 to $260.93 per metric ton with maximum current annual costs (1974) estimated to be $54,216,000. Implementation
of level II or level III technology can be achieved at an estimated cost to industry of $74,049,000.

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Waste Treatment
Waste Disposal
Waste Stream
Sludges
Crude Tank Bottoms
FCC Catalyst Fines
Disposal
Treatment

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Landspreading
Lagooning

17c. COSATI Field/Group

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1.0 EXECUTIVE SUMMARY

1.1 INTRODUCTION

This report is the result of a study commissioned by the United States Environmental Protection Agency (EPA) to assess the "hazardous waste practices of the petroleum refining industry." This industry study is one of a series by the Office of Solid Waste Management Programs, Hazardous Waste Management Division. The studies were conducted for information purposes only and not in response to a Congressional regulatory mandate. As such, the studies serve to provide EPA with: (1) an initial data base concerning current and projected types and quantities of industrial wastes and applicable disposal methods and costs; (2) a data base for technical assistance activities; and (3) a background for guidelines development work pursuant to Section 209, Solid Waste Disposal Act, as amended.

The definition of "potentially hazardous waste" as used in this study was developed on the basis of investigations and professional judgement of Jacobs Engineering Co. This definition does not necessarily reflect EPA thinking since it may not be applicable in other industries, or be suitable for regulatory guidelines. As used in this study, the criterion for hazard is the presence of a toxic substance above a threshold value. Obviously, the presence of a toxic substance should not be the sole determinant of hazardousness if there are known mechanisms to represent or illustrate actual effects of wastes in specified environments. Thus, the reader is cautioned that the data presented in this report constitute only the assessment of Jacobs Engineering Co. of hazardous waste management in this industry. EPA reserves its judgements pending a specified legislative mandate.

1.2 PURPOSE OF THE STUDY

This study was conducted with four basic objectives:

(1) To determine the source, nature, quantities and projected future quantities of potentially hazardous wastes generated by the petroleum refining industry.

(2) To examine and assess treatment and disposal practices currently employed within the industry.

(3) To consider improved technologies for waste treatment and disposal whose application would result in future reduction of waste hazard.

(4) To calculate the costs to industry for three levels of treatment and disposal technology, which are characterized as follows:

Level I	Technology currently employed by typical facilities;
Level II	Best technology currently employed on a commercial scale;
Level III	Technology necessary to provide adequate health and environmental protection.

1.3 STUDY METHODOLOGY

In pursuit of these objectives, the following procedures were utilized:

(1) A profile of the industry was developed after comprehensive review of the history, growth, refining processes, capacity, distribution and future trends of U. S. refineries.

(2) A representative sample of sixteen refineries was selected for study, field visits and waste stream sampling.

(3) Visits were made to selected refineries and waste samples were obtained.

(4) Chemical analysis of the samples was carried out to identify potentially hazardous constituents of refinery waste streams. A definition of hazardous wastes was established to enable identification of potentially hazardous waste streams.

(5) The composition and quantities of refinery-generated wastes were thus determined for the refineries sampled, and the data base was then expanded to the total industry.

(6) Average waste quantities (1974) were extrapolated to national, state and EPA Regional levels.

(7) A forecast of industry trends reflecting technologic and regulatory changes provided the basis for projections of waste generation and disposal practices for the years 1977 and 1983.

(8) **Cost information was developed for three levels of treatment and disposal technology (defined in Section 1.2). Costs are extrapolated to the entire industry on the basis of current waste management practices, as well as on those projected for the years 1977 and 1983.**

The study was conducted in four phases as follows:

Phase 1:	Industry Characterization (Section 2. 0);
Phase 2:	Waste Characterization (Sections 3. 0 and 4. 0);
Phase 3:	Treatment and Disposal Technology (Section 5. 0);
Phase 4:	Cost Analysis (Section 6. 0).

1.4 CHARACTERIZATION OF THE PETROLEUM REFINING INDUSTRY

1.4.1 Industry Description

As defined by the Standard Industrial Classification (SIC) Code 2911, a petroleum refinery is a complex combination of interdependent operations engaged in the separation of crude oil by molecular cracking, molecular rebuilding and solvent finishing, to produce a varied list of intermediate and finished products including gasoline, jet fuel, fuel oil, lube oil, grease, asphalt, coke, wax and others. Approximately 120 firms are engaged in petroleum refining in the United States. They comprise a total of 247 refineries (1974) with a daily processing capacity of approximately 14. 2 million barrels. These refineries vary in size according to production capacity within a broad range of between 150 barrels and 445, 000 barrels per day. Approximately one-third of U. S. refineries have a capacity of less than 10, 000 barrels per day, and these refineries represent in aggregate only 2. 5% of the total capacity of the industry. Refineries with a rated daily capacity greater than 150, 000 barrels, which represent only about 9% of the total number of U. S. refineries, account for 43% of the total industry capacity. Total annual employment for the industry numbers approximately 140, 000 and total industry-wide sales for domestically consumed petroleum products are estimated to be $30 billion (1974). The State of Texas has the greatest concentration of refineries, with a total of 40 facilities representing 16. 2% of the national total. California has 34 refineries and Louisiana, Illinois, Kansas, Oklahoma, Pennsylvania and Wyoming each have 10 or more. Refining capacity of individual states roughly parallels the number of facilities. Sixty-four percent of all U. S. refineries, or a total of 158 refineries, were constructed between the years 1944 and 1970.

1.4.2 Industry Characterization According to Refining Processes

For purposes of this study, the industry is characterized according to refining processes. This characterization was developed in an effort to classify refineries according to solid waste generation capacity, which is closely correlated with refinery complexity. Refinery waste streams are characteristic of certain continuous and intermittent processes. Intermittent process wastes generally result from the cleaning of refinery facilities and require disposal at intervals greater than two weeks. Typical of intermittent process wastes are storage tank bottoms and spent catalysts. Continous wastes result from wastewater treatment processes and unit processes, the former including bio sludges and dissolved air flotation float, and the latter including spent catalysts and catalyst fines and waste coke fines. They require disposal at intervals of less than two weeks. Since each of these waste types is associated with certain types of processes, four refinery categories were developed, each definitive of specific process types as follows:

Refinery Type	Processes Included
I	Crude vacuum distillation Liquified petroleum gas recovery Hydrotreating Hydrofining Reforming Alkylation Isomerization Visbreaking
II	All processes included in Type I in addition to: Fluid catcracking and hydroflowing

Refinery Type	Processes Included
III	All processes included in Type II in addition to: Fluid or delayed coking
IV	All processes included in Type III in addition to: Lube oil processing and Petrochemical operations

1.4.3 Refinery Distribution

Using the established characterization of petroleum refineries according to refining processes, the distribution of U.S. refineries has been carefully surveyed, and detailed tabular data appears in Section 2 of this report. Data is presented according to State and to EPA Regions for geographical location, daily capacity, employment, plant age, product slate and total crude capacity. A summary of refinery distribution by refinery types is given in the following table. Geographic distribution is shown for those states with ten or more refineries.

	REFINERY TYPE				
	I	II	III	IV	TOTAL
No. of Facilities	98	65	29	55	247
Geographic Location					
Texas	12	10	6	12	40
California	20	3	4	7	34
Louisiana	8	2	2	6	18
Oklahoma	3	2	2	4	12
Illinois	2	1	4	4	11
Kansas	2	4	3	2	11
Pennsylvania	3	2	0	6	11
Wyoming	3	5	1	1	10
Totals	53	29	22	42	147
Daily Capacity					
Under 5,600 m^3 (35,000bbl)	94	25	8	12	139
5,600 to 16,000 m^3 (35,000-100,000 bbl)	3	35	14	12	64
Over 16,000 m^3 (100,000bbl)	1	5	7	31	44
Employment					
1-50 employees	57	7	2	4	70
51-100	23	4	0	6	33
101-500	17	47	22	12	98
501-1000	0	6	5	13	24
Over 1000	1	1	0	20	22
Plant Age					
1-4 years	8	1	0	3	12
5-30	75	46	20	16	157
31-50	12	14	8	19	53
Over 50	3	4	1	17	25
Percentage of Total Crude Capacity	8.3	24.5	14.5	52.7	

Residual fuel oil and distilled fuel oil are produced by 227 and 226 refineries, respectively, or by approximately 92% of U. S. refineries. Motor gasoline is produced by 212 refineries (86% of the total), and unfinished oil by 172 (70%). Kerosene, including range oil, is produced by 154 refineries, and coke by 148. Sixty refineries, or less than 25% of U. S. total are engaged in the production of wax products, and only 18 refineries produce lubrication grease.

1.4.4 Future Trends in Petroleum Refining

Growth in U. S. refining industry crude capacity in the years 1973 and 1974 amounted to approximately one and one-quarter million barrels per day. Future growth in the industry will be affected by U. S. petroleum import policy, and demand for petroleum products, as well as by refinery construction costs and profit margin levels. Forecasts of future energy demands have been made on the basis of two probable economic patterns. The first is the highest attainable energy consumption level consistent with current world oil prices. It assumes recovery from the recession by mid-1976, and that no further government controls will be applied. The second is a pattern which would result from decontrol of U. S. crude oil prices and retention of the $3 per barrel oil import tariff initiated by the President. It assumes reduced consumption as a result of higher energy costs. To meet the energy demands which would be expected to result from these respectively increased or reduced consumption patterns, additional refinery capacity for the years 1974 through 1985 will be required as follows:

	High Demand	Reduced Demand
1974-1977	1583	1576
1978-1980	1464	103
1981-1985	860	349

Figures shown represent thousands of barrels per day.

This additional U.S. refinery capacity reflects balanced production in world geographic areas, and incremental requirements for processing Alaskan North Slope crudes.

1.5 THE ANALYTICAL PROGRAM

1.5.1 Criteria for Identification of Potentially Hazardous Wastes

The analytical program was conducted to identify potentially hazardous constituents of refinery waste streams, to determine whether they are present in refinery wastes, and to measure their levels of concentration. An initial list of potentially hazardous substances which required identification was contained in the original RFP issued by the Office of Solid Waste Management Programs. This list formed the basis for the analytical program, and included the following trace elements:

Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Selenium
Silver
Zinc

Also listed were certain groups of organic compounds, including carcinogens, pesticides, and chlorinated hydrocarbons. In-house knowledge of the petroleum refining industry and of trace metals characteristic of crude oil prompted addition to this list of four other potentially hazardous constituents of waste, i.e., nickel, vanadium, cobalt, and molybdenum. A total of fourteen trace elements were thus selected for identification, and for subsequent measurement of concentration levels in refinery waste streams. Examination of the samples to establish the chemical combinations of these elements was precluded by time and resource limitations.

The overall identification of potentially hazardous organic compounds which are present in petroleum refinery wastes was obtained by analysis of the oil fraction of these wastes, since it was concluded that "oil" per se is hazardous material. The rationale which provided the basis for this conclusion is discussed in a study of hazardous waste materials carried out for the EPA by Booz-Allen Applied Research, Inc. (1). Their report contained the conclusion that "oil" is potentially hazardous regardless of its individual constituents. Review of various published lists of hazardous substances (2, 3) led to a decision to add to the analytic program phenolic compounds, ammonium compounds, fluorides and strong acids and alkalis, all of which have been a focal point of many environmental concerns. Pesticides were not included in the program, since they are not present in petroleum and are not produced by refineries.

Preliminary examination of fourteen waste samples using gas liquid chromatography and mass spectroscopy confirmed an absence of chlorinated hydrocarbons in refinery wastes. This class of compounds was, therefore, eliminated from subsequent analytical consideration.

A review was undertaken to assess the degree of probability that the wastes might contain carcinogens. The chemical classes of nitrogenous hydrocarbons and polyneuclear aromatics, commonly considered to be carcinogens, have been extensively studied because of concerns related to automobile exhaust emissions. It is apparent from these studies that the nitrogen compounds in petroleum are not of the cancer-forming type, viz, the amines and nitrosamines, nor is there evidence that naturally occurring nitrogen compounds are transformed to carcinogens either by combustion or by natural processes*. Nitrogen compounds were therefore not included for study in the analytical program. Polynuclear aromatics, on the other hand, are known to occur in crude oils, and although only a small fraction of the amount present is carcinogenic, it was decided that these compounds should be included in the analytical program. Analysis of polynuclear aromatics was limited to benz-A-pyrene which is probably the only one of potentially hundreds of isomers which has been studied sufficiently to enable a creditable analysis to be performed. It is probable, furthermore, that a near-constant ratio exists between benz-A-pyrene and total polynuclear aromatics. If this is so, benz-A-pyrene may prove to be a valuable indicator of the total carcinogeneity of oily wastes.

1.5.2 Analytical Methods and Quality Control Procedures

Samples of seventeen waste streams from sixteen refineries were thus evaluated for constituent concentrations of fourteen identified trace elements and for oil, phenolic and ammonium compounds, strong acids and alkalis, fluorides, and benz-A-pyrene. The analytical program was conducted with the use of standard methods recognized by the American Petroleum Institute (API), the American Water Works Association (AWWA), and the American Organization of Analytical Chemists (AOAC). Selected detection limits for trace elements are the average levels found in the soil environment, and concentrations in the wastes are measured against this background level.

The relevance of leachate analysis to the study of potentially hazardous wastes was carefully considered, and it was concluded that such analyses are not within the scope of this study. In vitro leachability of inorganic substances is not an accurate indicator of their solubilization potential in the biological environment, nor is it a measure of ultimate hazard. Ultimately, it is the presence of a toxic substance rather than its chemical state which determines its potential hazard.

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*Source: Chevron Research, Richmond, California (private communication). Robert LeTourneau, Chevron Research, to contractor. October 10, 1974.

Verification of the accuracy of laboratory results was carried out using three control methods. The first method provides a measure of the error introduced by extensive pretreatment steps required prior to actual determinations, and involves the use of known concentrations of trace elements which are prepared in water and are subjected to the same digestion and preparative procedures as the refinery samples. The second method was employed to verify accuracy in measuring concentration levels of selected elements in refinery samples, and involves the addition of known quantities of these elements in the samples. The third method involves performing duplicate determinations, and was carried out routinely on ten percent of refinery samples. Additional checks of accuracy were achieved by the comparison of results obtained in the Jacobs Engineering Co. laboratory with those obtained by refinery laboratories on identical or "split" samples. A broad measure of agreement is found in values reported.

1.6 WASTE CHARACTERIZATION

1.6.1 Refinery Waste Streams

Following is a listing of individual process wastes of the petroleum refinery industry:

(1) Crude tank bottoms
(2) Leaded or non-leaded tank bottoms
(3) API separator sludge
(4) Neutralized HF alkylation sludge
(5) Kerosene filter clays
(6) Once-through cooling water sludge
(7) Dissolved air flotation float
(8) Slop oil emulsion solids
(9) Spent lime from boiler feedwater treatment
(10) Cooling tower sludge
(11) Exchanger bundle cleaning sludge
(12) Waste bio sludge
(13) Storm water silt
(14) Fluid catalytic cracker (FCC) catalyst fines
(15) Coke fines
(16) Lube oil filter clays
(17) Spent catalysts
(18) Chemical precipitation sludge
(19) Vacuum filter or centrifuge cake
(20) Silica gel

All of these waste streams are described in detail in Section 4.3 of this report. The first thirteen of these wastes are generated by Type I refineries. Type II refineries generate, in addition, fluid catalytic cracker (FCC) catalyst fines. Type III refineries also generate FCC catalyst fines and coke fines. All of the above-mentioned waste streams are found in Type IV refineries. Waste streams numbered 17 through 20 above have not been included in the analytic tables which appear in Section 4.0 of this report. Spent catalysts are not included because a large proportion are sent to processors for recovery of valuable metals. Chemical precipitation sludge results largely from tertiary treatment systems which currently are not widely used. Vacuum filter or centrifuge cake is a combination of waste streams 3 and 7, both of which appear in the tables. Silica was present in very limited quantity in the waste of only one of the participating refineries. It was concluded that it is not a characteristic refinery waste, and in addition it does not contain identified hazardous substances.

A number of variables associated with refinery operations may affect the composition and quantity of specific solid waste streams. One of these variables is the type of crude feedstock. The constituents of crude oil may vary widely, and its heavy metal content, for example, has a significant effect upon the potentially hazardous metal content of crude oil storage tank bottoms, of waste FCC fines, and of the various wastewater treatment plant sludges. Another variable of petroleum industry operations is found in process units. Differences in wastewater and air pollution control processes, for example, may markedly affect the quantity as well as the composition of potentially hazardous waste material. A hydrofluoric alkylation unit, for example, produces a sludge high in fluoride, while a sulfuric acid alkylation unit does not generate large quantities of fluoride in waste sludge. A third important variable is the age of processes, which refers to the general level of technology used in the process rather than to the length of time the process has been in service. The use of air and water pollution control devices, such as an electrostatic precipitator on a fluid catalytic cracker, increases solid waste quantity by removing particulate matter which would otherwise be an air pollutant. The use of a Bender treater, or of hydrotreating to treat kerosene rather than the use of clay filters for this purpose will drecrease the quantity of solid waste generated. Still another variable of waste quantity generation is that of operational practices and control. Reclamation of spent catalysts used in metal recovery, the use of filter clay for road construction, and improved material handling procedures may significantly reduce the quantity of waste generated by a refinery.

1.6.2 Definition of Hazardous Wastes

For purposes of this study, a definition was derived for "hazardous wastes." Since the extent of potential hazard which a waste may represent is a reflection of the concentration as well as the quantity of its potentially hazardous constituents, both measurements were made of the identified constituents in refinery wastes. Concentration levels of these waste constituents were measured against a standard for toxicity which was the average concentration of these substances in soil. This standard was selected because most wastes emanating from refineries are destined for land disposal. Hazardous wastes were defined as those with at least one component with concentration levels exceeding the average level in the natural soil environment. Since each refinery waste stream contains a minimum of three potentially hazardous components with concentration levels exceeding those in soil, all are considered to be hazardous. Except for minor variations, waste streams of all refinery types have equivalent numbers of components at concentrations above background.

1.6.3 Current and Projected Waste Quantities

To ascertain ultimate hazard represented by refinery generated wastes, the quantity of each hazardous constituent generated was measured in each of the waste streams and was expressed in terms of metric tons per year per thousand barrels per stream day (MBSD). Oil is the principal hazardous substance in refinery wastes, representing approximately 110,000 metric tons (MT) per year (1974). Metal constituents in refinery wastes represent an annual total of 250 MT industry-wide, of which approximately 35% or 87 MT is chromium, 31% or 78 MT is zinc, 9% or 23 MT is nickel, 9% or 22 MT is copper and 8% or 20 MT is vanadium. The remaining 9% consists primarily of lead, arsenic, molybdenum, cobalt, selenium, mercury, silver and cadmium.. Fluoride emission amounts to 812 MT; phenol, 5 MT; cyanide, 1 MT; and benz-A-pyrene, 0.1 MT. (See Table 43, p. 111.)

Because of expanding use of gasoline and other petroleum based products, as well as the desire to reduce imports of petroleum products, increased growth in the petroleum refining industry is expected through the year 1983. Most of the major effects of water and air regulation on quantities of potentially hazardous refinery wastes have already been experienced by the petroleum industry. While some additional quantities of potentially hazardous wastes are expected to be generated as a result of the application of 1977 and 1983 regulations, they will, in general, be small compared with quantities currently generated. Additional wastes which are expected to be generated in significant quantities are the FCC catalyst fines from those refineries which will be installing electrostatic precipitators or some other air pollution control technology, and waste bio sludge which will result from new installations of secondary wastewater treatment systems.

Quantities of potentially hazardous wastes and hazardous waste constituents projected for the years 1977 and 1983 are based upon the following considerations:

(a) Additional refineries are expected to use secondary biological treatment and air flotation systems in 1977 and 1983.

(b) Certain wastes, such as slop oil emulsion solids, are expected to be reduced in quantity as a result of increased oil recovery.

(c) Environmental regulations are expected to result in reduced use of such elements as chromium and zinc in cooling towers, and of lead in gasoline.

(d) Projected increases in crude oil capacity are expected to result in parallel increases in waste production associated with fluid catalytic cracking, coking, hydrogen fluoride alkylation, and lube oil processing.

Taking into account the projected increase in number of refineries and resulting expanded capacity, current and projected gross constituents of potentially hazardous refinery waste streams are shown in the following table with figures given in metric tons (wet weight basis):

	1974	1977	1983
Water	1,132,092	1,126 ,174	1,077, 438
Solids (Including Hazardous Constituents)	624,541	714,834	810,756
TOTAL	1,756,633	1,841,008	1,888,194

Further breakdown of these quantities according to states and EPA Regions is shown in Table 1.

1.7 TREATMENT AND DISPOSAL TECHNOLOGIES

1.7.1 Introduction

Petroleum refineries generate nearly 625,000 metric tons per year of potentially hazardous waste (dry weight), and ultimately, all wastes are disposed of to land. Treatment and disposal methods used by the industry are contingent upon the nature, concentration, and quantities of waste generated, as well as upon the presumed hazardousness of these materials. They are further affected by geographic conditions, transportation distances, disposal site hydrogeological characteristics, and regulatory agency requirements. (Those wastes which are recovered as marketable or recycled products cannot be regarded as hazardous, and consequently are not within the scope of this study.) At the present time, 63% of these wastes are disposed of by landfilling, 28% by lagooning, 7% by landspreading, and 2% by incineration. Approximately 40% of refinery wastes are managed onsite; 60% of wastes are hauled by private contractors to offsite disposal locations. Of those refinery wastes which are handled onsite, 45% are disposed of by landfilling, 33% by lagooning, and the remainder by landspreading and incineration. Offsite land disposal is nearly always carried out in a county or municipal sanitary landfill. Treatment methods are designed for transformation, reduction, or

TABLE 1

CURRENT AND PROJECTED QUANTITIES OF PETROLEUM REFINING INDUSTRY WASTES (metric tons per year)

	1974			1977			1983		
	TOTAL POTENTIALLY HAZARDOUS WASTE*		TOTAL HAZARDOUS CONSTITUENTS	TOTAL POTENTIALLY HAZARDOUS WASTE*		TOTAL HAZARDOUS CONSTITUENTS	TOTAL POTENTIALLY HAZARDOUS WASTE *		TOTAL HAZARDOUS CONSTITUENTS
	Dry Basis	Wet Basis	Dry Basis	Dry Basis	Wet Basis	Dry Basis	Dry Basis	Wet Basis	Dry Basis
ALASKA	2390	7280	480	3270	9300	620	3240	8190	520
ALABAMA	1300	3950	260	1290	3630	250	1280	3230	210
ARKANSAS	2590	7180	440	2980	7630	460	3140	7250	410
ARIZONA	360	1110	70	360	1020	70	360	900	60
CALIFORNIA	75990	216300	13690	90070	236190	15000	94290	221110	13310
COLORADO	2180	6330	410	2390	6290	410	5560	13330	830
DELAWARE	5770	16390	1040	8260	21670	1410	12290	29090	1790
FLORIDA	1920	5100	380	1910	4910	360	1890	4650	300
GEORGIA	520	1580	100	520	1450	100	510	1290	80
HAWAII	2670	7880	510	2740	7340	480	2720	6530	400
ILLINOIS	47170	135200	8770	50360	131180	8600	60920	143160	8900
INDIANA	23870	67760	4270	27220	70750	4510	35550	83670	5060
KANSAS	25230	64370	3740	27500	65680	3830	29150	64600	3560
KENTUCKY	6200	18100	1170	6440	16950	1100	6390	15090	920
LOUISIANA	77230	212920	13340	89930	227280	14360	103720	238240	14220
MARYLAND	880	2690	180	880	2470	170	870	2190	140
MICHIGAN	5430	15970	1040	5590	14900	980	5540	13250	820
MINNESOTA	7490	21670	1400	7730	20270	1330	7670	18060	1120
MISSOURI	4160	12010	770	4330	11270	730	4300	10040	610
MISSISSIPPI	10840	32080	2080	11070	29840	1970	10980	26510	1650
MONTANA	6430	18410	1220	6890	17850	1190	13770	32390	2040
NEBRASKA	2070	6000	390	2160	5630	360	2140	5010	310
NORTH DAKOTA	2170	6160	400	2300	5820	380	2280	5210	320
NEW JERSEY	25790	73310	4640	27170	69430	4390	27030	62340	3710
NEW MEXICO	2990	7080	420	3680	7300	400	3660	6670	340
NEW YORK	4180	12140	780	4360	11390	740	4320	10150	620
OHIO	23390	67490	4380	26420	69160	4530	34230	80440	4960
OKLAHOMA	21770	60180	3840	25800	65520	4220	28180	64970	3970
OREGON	520	1580	100	520	1450	100	510	1290	80
PENNSYLVANIA	33600	92490	5700	42210	108830	6880	42190	98860	5900
TENNESSEE	1180	3370	230	1220	3160	220	1210	2830	180
TEXAS	164490	462380	28950	192500	495330	31300	216010	502100	29850
UTAH	5170	14830	970	5420	13960	910	5380	12470	770
VIRGINIA	2190	6230	400	2300	5860	370	2280	5230	310
WASHINGTON	13810	40140	2600	15640	41600	2730	19190	46350	2890
WISCONSIN	1380	4060	270	1420	3790	250	1410	3370	210
WEST VIRGINIA	2010	4440	140	2330	5010	150	2830	5720	160
WYOMING	7190	20510	1320	7650	19860	1270	13740	32410	1990
TOTAL	624540	1756630	110890	714820	1841020	117130	810750	1888200	113560

EPA REGION

I	0	0	0	0	0	0	0	0	0
II	29960	85450	5420	31520	80820	5130	31350	72490	4330
III	44450	122230	7450	55970	143850	8980	60470	141090	8300
IV	21970	64180	4230	22450	59950	3990	22260	53610	3360
V	108740	312150	20130	118740	310040	20190	145320	341950	21080
VI	269070	749730	46990	314890	803070	50740	354710	819240	48780
VII	31450	82380	4900	33990	82580	4920	35590	79660	4480
VIII	23150	66230	4310	24660	63790	4180	40730	95790	5960
IX	79030	225280	14280	93170	244550	15550	97370	228540	13770
X	16720	49000	3180	19430	52360	3450	22950	55830	3500
TOTAL	624540	1756630	110890	714820	1841020	117130	810750	1888200	113560

* Total Potentially Hazardous Waste = Total Waste

immobilization of oily and organic waste components, and include landspreading, employed for aerobic biological oxidation of oily organic wastes, and for photochemical oxidation of tetraethyl lead wastes; incineration for chemical oxidation of organic wastes; and chemical fixation processes which immobilize wastes by physical-chemical means.

1.7.2 Current Treatment/Disposal Technologies

Landfilling is presently the most widely used method for disposing of petroleum refinery wastes. The environmental adequacy of this method varies not only with the characteristics of generated wastes, but also with operational procedures and with site geologic and climatologic conditions. Among the many factors which affect landfilling operations are the following: (1) the extent of solid waste segregation; (2) the extent of liquid and solid waste mixture; (3) the extent to which acids or caustic sludges are neutralized; (4) the size of the active fill area; and (5) quality of the routing of the ground and surface waters around the landfill site.

Landspreading is a treatment/disposal method which is relatively inexpensive and which is experiencing increasing use by refineries for disposing of oil-contaminated wastes. Studies of methods of land disposal of oil wastes skimmed from oceans or beaches, or from accidental transport vehicle spills within the country have suggested that landspreading of such material is an economical and effective means of disposal which would be well-suited for disposal of refinery-generated wastes as well.* Microorganisms, using hydrocarbons in oily sludges as a substrate for their growth, quickly degrade the oil, changing it from an oily, odorous sludge to a dried, cracked, soot-like material which crumbles easily. While the oily sludge material does not decompose and disappear completely, the oil conditioned soil appears to have a higher moisture content than native soil, and a reduced iron and aluminum content. Soil productivity may actually be enhanced by light applications of oils.* A number of refinery-sponsored studies designed to evaluate the landspreading procedure or its effect on plant growth are planned or underway. One refinery is planning to investigate landspreading to determine optimum operating procedures of this technology. Data currently available, however, indicates that landspreading is emerging as an important method for disposal of refinery wastes.

*Source: Jacobs Engineering Company.

Lagoons, ponds, sumps, and open pits have been used for waste disposal by the petroleum refining industry for many decades. In the past, when convenience and easy accessibility rather than environmental considerations dictated disposal site locations, it was not uncommon to find sumps and ponds near the refinery process units or at the back of refinery property. With progressively increasing volumes of waste, many of these sites were filled up and abandoned, and disposal expediency of the past became a major problem in many parts of the country. Certain considerations, such as growing land requirements for refinery expansion, increasing land costs, and increasingly stringent regulatory agency requirements, have resulted in phasing out the use of sumps and lagoons as primary disposal methods, and in a shift to landspreading and landfilling. Of the sixteen refineries visited, only one made use of a lagoon for the disposal of an appreciable portion of its wastes. Two other refineries have recently instituted the use of sumps as a temporary expedient method of disposing of tank bottoms and spilled oily material.

Special procedures have been developed for the exclusive treatment and disposal of leaded gasoline sludges which accumulate in aviation and motor gasoline storage tanks as a result of oxidation and polymerization reactions accelerated by light and heat. While the volume of this sludge is quite small and tank cleaning consequently quite infrequent, the organic lead vapors of various lead alkyl-additives in gasoline are known to be toxic at very low concentrations. Two basic procedures were encountered for disposal of leaded gasoline sludge from product gasoline storage tanks. These are described in Section 5. 3. 4. Degradation of buried tetraethyl leaded gasoline sludge is very slow, and probably not complete. Spreading on the soil surface for an indefinite period of weathering in the presence of sunlight and air has been recommended as a means of achieving greater evaporation of volatile fractions.*

The use of incineration for disposal of potentially hazardous refinery wastes appears to be confined to certain parts of the country in which hydrogeologic and climatologic conditions preclude the use of other methods and in which land shortages or high land costs preclude land intensive treatment and disposal methods. It is also a viable volume-reduction method which can be employed in areas where hauling distances are large, or for certain reclaimable wastes which cannot be handled economically in another way. Thermal energy contained in oily wastes can also be used to destroy certain other waste streams not easily treated using any other method. Most refineries which operate incinerators are located in the Midwest, the Great Lakes Region, and the Northeast. However, the process is unpopular among refinery managers and plant engineers because of its high initial capital costs as well as high recurring annual operational and maintenance costs. Furthermore, the thorough extraction of oil from waste streams which has resulted from the increased value of oil, has substantially decreased the thermal value of the various refinery sludges, and the implementation of increasingly stricter air pollution requirements is expected to mandate expensive and complicated air pollution control devices in the future.

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*Source: Ethyl Corporation (A technical communication). K.C. Jost, Ethyl Corporation, to contractor. January 1974.

Two other little-used disposal methods are deep well injection and ocean disposal. The former method was practiced by only one of sixteen refineries visited. Approximately 186.5 million gallons per year of sulfidic solution generated by caustic washing of crude cracking and hydrotreating streams, sour water from a hydrotreating unit, brines from the desalter operation, and other weak solutions from crude processing and pretreating, are first neutralized and pumped through a mixed media filtration unit before injection into a subterranean formation. Ocean disposal of certain hazardous wastes is prohibited, and permits to use this method for other less hazardous wastes are becoming increasingly difficult to obtain.

Certain special treatment methods are employed by the refining industry for the transformation, reduction, or immobilization of oily and organic wastes. The use of polyelectrolytes to reduce the volume of crude tank bottoms was observed in at least one of the refineries visited. "Off-gas" from field wells is mixed with crude sludge and heated to a temperature of approximately 130 F. Polyelectrolytes are added and the contents mixed. The crude sludge is broken down into a very distinct oil fraction and an underlying clear water fraction, both of which are separately decanted from the tank. As a result, the residual sludge requiring removal from a 125,000 barrel tank amounted to a mere seven barrels. Another special practice observed in treatment of both liquid and solid refinery wastes is that of chemical fixation. This method is employed to produce a chemically inert precipitate which is usually removed by vacuum truck, and it is helpful in overcoming the fluidity of certain petroleum wastes. Chemical fixation or solidification is used by a few refineries to solve specific disposal problems, such as permanent disposal of the contents of environmentally unacceptable lagoons filled with API separator bottoms or crude tank bottoms. The stability of waste materials which have undergone chemical fixation under actual environmental conditions is as yet uncertain.

The use of each of the three established levels of treatment and/or disposal technology (defined in Section 1.2) is applied to each refinery waste stream, and is assessed with regard to monitoring capability, compatibility with existing facilities and processes, implementation and energy requirements and environmental adequacy. This data is presented in Section 5.0 of this report in Tables 49 through 65.

1.7.3 Safeguards in Treatment and Disposal

Various precautionary measures are taken by the petroleum refining industry to guard against immediate or future injury to the environment resulting from treatment and disposal practices. The use of a site classification system* for offsite landfilling is one of the most comprehensive methods presently employed to safeguard groundwater quality and the surrounding environment. Stringent site selection criteria, including soil permeability, depth and distance to useable groundwater aquifers, materials to be disposed, geologic formations, and climate and hydrogeology, are generally applied.

Mandatory minimum requirements for site management and operation are generally monitored by state or local regulatory agencies, and sites typically operate under renewable permits. In California, Texas and a few other states, petroleum refinery wastes must be placed in a secure Class I or conventional Class II landfill site, and there appears to be a recent trend toward mandatory offsite monitoring of groundwater quality. Several other states are in

*Such systems are currently being used by several State and local governments as a part of the site selection process.

the process of enacting enabling legislation which would provide for suitable environmental safeguards. Major safeguards employed in onsite landfilling include the use of hydrogeologically suitable sites, the construction of storm runoff diversion ditches, and careful adherence to accepted operating practices. The use of bentonite clay, which is presumed to have high ion exchange capability and low permeability, was observed underlying the onsite landfill area of two of the visited refineries. Both sites provided excellent peripheral surface drainage, a small exposed working surface, and an impermeable clay covering mounded in the center to shed runoff water.

The use of safeguards in landspreading appears to be limited to the construction of dikes or low-level berms surrounding the spreading surface. Since landspreading is a relative innovation among petroleum refinery disposal practices, many of the facilities are operating on a trial basis, and the development of safeguards has not as yet been extensively explored. The majority of refinery landspreading sites observed had not as yet instituted controls on surface water-transport of oil or other hazardous constituents of refinery wastes. One of the experimental facilities employed upstream and downstream monitoring wells for the detection of leachates and analysis of intermediate degradation by-products.

The majority of lagoons and sumps used for refinery waste disposal are constructed from native earth materials. The use of concrete, plastic, or clay liners to reduce or impede the exfiltration of potentially hazardous liquids was the only safeguard which was observed, and was employed in few facilities.

In the single example of deep well injection actually observed during the course of the refinery field visits, the two major safeguards employed were those of location and depth selection. A description of construction plans and geological reports confirming the suitability of the site were required by the state regulatory agency. Various types of air pollution scrubber systems were employed in many of the incineration units. One of the units observed employed especially designed burners and a special injection feed system for controlled burning of the very viscous sludge residues and other types of petroleum refinery wastes. The use of devices for the detection and control of excess oxygen, or of temperature monitoring systems in hearths, stacks, and combustion zones are additional safeguards sometimes employed.

To avoid toxicity from vapor inhalation, special precautions are exercised in disposal of leaded gasoline sludges. Breathing equipment and tank ventilation systems are used to protect men working within the tanks, and a drainage sump is excavated around the tanks. Entrance to the diked area is generally prohibited until the vapor concentration has been reduced to levels below 20 parts per million. Access to degraded leaded gasoline sludge disposal areas or to concrete weathering pads employed in the newer disposal procedure is precluded by the presence of a locked chain-link fence. These weathering pads are typically elevated one or more feet above the surrounding terrain to minimize the quantity of storm runoff which washes across the pad. A peripheral curbing of at least six inches in height is constructed for sludge containment, and the entire slab is sloped to assure drainage to the plant wastewater collection system.

1.7.4 Future Trends in Waste Management Practices

It is anticipated that the coming years will see significant changes in the present solid waste management practices employed by the petroleum refining industry. Projections indicate increased recycling and reclamation of materials used in the refining process, as well as considerable waste reduction as a result of improved technology and increased product recovery. It is anticipated that the next decade will bring a dramatic decrease in the amount of offsite disposal with a concommitant shift to onsite disposal, particularly in landspreading and landfilling. Lagooning is expected to decrease slightly, with minor increases in incineration and special onsite disposal practices. These changes are expected to result from dynamic interactions between environmental regulations, the development of new technologies, particularly in landspreading and in fluidized bed incineration, and the new economics surrounding energy shortages which encourage oil reclamation and general conservation in operational procedure and disposal techniques.

1.8 TREATMENT AND DISPOSAL COSTS

The cost of treatment and disposal of each potentially hazardous solid waste generated by a typical refinery with a capacity of 100,000 barrels per day has been calculated using three different levels of technology. Industry costs for each of these levels of technology are then extrapolated to the entire petroleum refining industry, based upon the use of current management practices, and projections are also made on the basis of practices expected for 1977 and 1983.

Investment and operating costs are based upon discussions with industry representatives in the course of refinery visits, and on information obtained from waste treatment and disposal contractors, from state public utility commissions, from the Federal Interstate Commerce Commission, and from available literature. Wherever possible, costs are based on actual installations, or on price quotations from waste treatment manufacturers and disposal contractors. In the absence of such information, cost estimates are developed on the basis of plant-supplied costs for similar treatment and disposal operations.

All cost estimates are representative of fourth calendar quarter 1973 prices, with annualized capital costs assumed to be 10% of total capital investment. Interest costs have been calculated at 10%, and depreciation costs have been calculated on the straight-line method according to the useful service life of treatment and disposal equipment.

For purposes of this study, land cost is held constant at $12,350 per hectare (10,000 square meters or 2.471 acres), or the equivalent of approximately $5,000 per acre. This figure assumes increased costs associated with special procedures in secure landfilling and landspreading operations or in use of additional special safeguards. It also takes into account ultimate market value and capital recovery based upon land availability following use for waste disposal.

The estimated unit costs for Level I technology varies from $3.33 per metric ton (dry weight) for onsite disposal in excavated pits of leaded gasoline tank sludge to $239.81 per metric ton for secure landfilling of waste biosludge. Corresponding unit costs for Level II technology is $4.36 per metric ton for onsite soil spreading in dike areas with subsequent rotodisking into soil of leaded gasoline tank sludge, to $260.93 per metric ton for secure landfilling of DAF float. Estimated unit costs for Level III technology vary from $1.80 per metric ton for special treatment of crude tank bottoms to $260.93 per metric ton for secure landfilling of DAF float. The maximum annual cost to industry for current disposal is estimated to be $54,216,000 per year, representing approximately 0.18% of 1973 total industry revenue of $30 billion. The maximum annual cost to industry for implementing either Level II or Level III technology is estimated to be $74,049,000 or approximately 0.25% of total annual revenues (1973).

2.0 CHARACTERIZATION OF THE PETROLEUM REFINING INDUSTRY

2.1 INDUSTRY DESCRIPTION

2.1.1 Characterization by Product Slate (Standard Industrial Classification)

The petroleum refining industry in the United States may be characterized in various ways. It has been defined according to product slate, by the Standard Industrial Classification (SIC) Code Number 2911 of the United States Department of Commerce. Among the numerous intermediate and finished products with their respective SIC Code Numbers are the following:

Product	SIC Code
Aviation Gasoline	29111-11
Motor Gasoline	29111-31
Naphtha Jet Fuel	29112-11
Kerosene Jet Fuel	29112-13
Kerosene, including Range Oil	29113-11
Distilled Fuel Oil	29114-11
Residual Fuel Oil	29115-11
Liquified Refinery Gases	29116-11
Other Aliphatics	29116-31
Lube Oil	29117-21
Lubrication Grease	29117-31
Unfinished Oil	29118-13
Petrochem Naphtha	29118-15
Petrochem, Others	29118-51
Asphalt	29119-11
Coke	29110-21
Road Oil	29110-31
Refinery Still Gas	29110-41
Special Naphtha	29110-51
Microcrystalline Wax	29110-61
Crystalline, Refined Wax	29110-71
Crystalline, Other	29110-81
Other Finished Products	29110-98

The production of crude oil or natural gas from wells, and the production of natural gasoline, as defined by the SIC Code Number

1311, are not within the scope of this study. Also excluded are distribution and transportation activities, as well as all other operations associated with such production.

2.1.2 Description of Manufacturing Processes

A complex combination of inter-dependent processes form the basis of refinery operations. Twenty-one fundamental processes are essential in the production of final and intermediate products from crude oil. These are described briefly in a sequence characteristic of typical refinery process flow:

Crude Oil and Product Storage - Storage tanks of varying size provide adequate supplies of crude oils for use in primary fractionation, equalizing process flows, feedstocks for intermediate processing units, and in the storage of final products prior to shipment. Water which separates from crude oil or its products during storage is drawn off to the refinery oily water sewer system.

Crude Oil Desalting - Electrostatic and chemical processes are employed for removing inorganic salts and suspended solids from crude oil prior to fractionation. The crude oil is mixed with water to form an emulsion, which is broken by the action of an electrostatic field or specific deemulsifying chemicals. The process separates the salts and other impurities from the crude oil, and the contaminated water is discharged to the refinery oily water sewer.

Crude Oil Fractionation - Distillation is used to separate crude oil into light overhead products (i.e., gases and gasoline, kerosene, heating oil, and lube oil), sidestream distillate cuts, and reduced crude bottoms. The trend is toward more complex combinations of atmospheric and vacuum towers with more individual sidestream products. The crude oil fractionation stills provide feedstocks for the downstream processing units as well as some final products.

Thermal Cracking - This process includes visbreaking and coking as well as regular thermal cracking. In each of these operations, heavy oil fractions are broken down into lighter fractions such as domestic heating oil, catalytic cracking stock, etc., by the action of heat and pressure. Heavy fuels or coke are produced from the uncracked residue. Regular thermal cracking, which was an important process before the development of catalytic cracking, is being phased out; visbreaking and coking units are installed in a significant number of refineries, and their application is expected to increase.

Catalytic Cracking - This process, like thermal cracking, breaks heavy fractions (principally gas oils) into lighter fractions, and is probabily the key process in the production of large volumes of high-octane gasoline stocks, furnace oils, and other useful middle distillates. The use of a catalyst permits operation at lower temperatures and pressures than those of thermal cracking, and also inhibits the formation of undesirable polymerized products. Fluidized catalytic cracking processes, in which the finely-powdered catalyst is handled as a fluid, have, in most cases, replaced the fixed-bed and moving-bed processes, which use a beaded or pelleted catalyst. The types of catalyst used in this process include alumina, clay, copper, iron oxide, magnesia, potassium, and silica alumina.

Hydrocracking - Basically, hydrocracking is an efficient, low-temperature, catalytic method of converting refractory middle-boiling or heavy sour feedstocks into high-octane gasoline, reformer charge stock, jet fuel and/or high grade fuel oil. Hydrocracking has a high degree of flexibility in adjusting operations to meet changing product demands. It is one of the most rapidly growing refinery processes. The types of catalysts commonly used are tungsten sulfide-silica alumina, iron-HF clay, and nickel-silica alumina.

Reforming - Reforming is a process of molecular rearrangement to convert low-octane feedstocks to high-octane gasoline blending stock, or to produce aromatics for petrochemical uses. Multireactor, fixed-bed, catalytic processes have almost completely replaced the older thermal process. There are many variations, but the essential difference is the composition of the catalyst involved. The types of catalyst commonly used in this process are alumina, cobalt molybdate and oxide, molybdenum, platinum, and silica-alumina.

Polymerization - This process converts olefin feedstocks (primarily propylene) into a higher molecular weight polymer gasoline. It is presently being used by only a small number of refineries because the product octane is not sufficiently higher than that of the basic gasoline blending stocks to significantly upgrade the overall motor fuel pool. Also alkylation yields per unit of olefin feed are much better than polymerization yields. Consequently, the current polymerization downtrend is expected to continue. Catalysts utilized include copper pyrophosphate and phosphoric acid.

Alkylation - Alkylation is the reaction of an isoparaffin (usually isobutane) and an olefin (propylene, butylene, etc.) in the presence of a catalyst to produce a high-octane alkylate, which is one of the most important components of automotive fuels. Sulfuric acid is the most widely used catalyst, although hydrofluoric acid and aluminum chloride are also used. Alkylation process capacity is expected to continue to increase with the demand for high-octane gasoline.

Isomerization - Isomerization is another molecular rearrangement process which is very similar to reforming. The charge stocks generally are lighter and more specific (normal butane, pentane, and hexane. The catalysts used are aluminum chloride, antimony chloride, bauxite, cobalt molybdate, hydrochloric acid, and silica-alumina. The desired products are isobutane for alkylation feedstocks and high-octane isomers of the original feed materials for motor fuel.

Solvent Refining - Solvent refining includes a large number of alternative subprocesses designed to obtain high-grade lubricating oil stocks or aromatics from feedstocks containing naphthenic, acidic, organometallic, or other undesirable materials. Basically, it is a solvent extraction process dependent on the differential solubilities of the desirable and undesirable components of the feedstock. The principal steps are countercurrent solvent extraction, separation of solvent and product by heating and fractionation, removal of trace solvent from the product, and solvent recovery.

Dewaxing - This process removes wax from lube oil stocks, generally after deasphalting and solvent refining, to produce lubricants with low pour points, and to recover microcrystalline wax. Except for pressing and sweating, a process now used very little, the various dewaxing processes involve use of solvents, principally methylethylketone (MEK), for extraction of wax. Solvent is introduced into the waxy distillate stream at selected points in the chilling equipment. The wax is then removed in vacuum filters. Through selection of feedstocks and variation of operating conditions, emphasis can be shifted from dewaxing of a lube oil stock to deoiling of a wax stock.

Hydrotreating - This process is used to remove sulfur compounds, odor, color and gum-forming materials, and other impurities from a wide variety of petroleum fractions by catalytic action in the presence of hydrogen. In most subprocesses, the feedstock is mixed with hydrogen, heated and charged to the catalytic reactor. The reactor products are cooled, and the hydrogen, impurities, and high grade product, separated. Hydrotreating was first used primarily on lighter feedstocks, but with more operating experience and improved catalysts, hydrotreating has been applied to increasingly heavy fractions such as lube oils and waxes. Along with hydrocracking, it is one of the most rapidly growing refinery processes. Among the catalysts most commonly used in hydrotreating are alumina, cobalt molybdate, nickel sulfide platinum, silica alumina, and tungsten nickel sulfide.

Deasphalting - Deasphalting removes asphalt or resins from viscous hydrocarbon fractions, such as reduced crude, to produce stocks suitable for subsequent lube oil or catalytic cracking processes. The asphaltic materials are extracted through the use of a solvent, generally propane. The process is carried out in an extraction tower, where pipe still bottoms or other heavy stock are mixed with propane. After asphalt has been removed from crude oil or other bottom products, the propane is recovered.

Drying and Sweetening - Drying is a process concerned primarily with removal of sulfur compounds, water, and other impurities, from gasoline, kerosene, jet fuels, domestic heating oils, and other middle distillate products. "Sweetening" is the removal from these products of hydrogen sulfide, mercaptans, and elemental sulfur, which impart a foul odor and/or decrease the tetraethyl lead susceptibility of gasoline: The major sweetening operations are oxidation of hydrogen sulfide to disulfides, removal of mercaptans, and destruction and removal of all sulfur compounds, including elemental sulfur. Drying is accomplished by salt filters or adsorptive clay beds. Electric fields are sometimes used to facilitate separation of product from treating solution.

Wax Manufacture - The fractionation process currently in wide use in production of paraffin, and occasionally of microcrystalline waxes of low oil content, is similar in most respects to MEK dewaxing. Principal differences are use of a solvent or solvent mixture more suitable to the crystallization and separation of paraffin wax, and a more complicated crystallization-filtration flow involving redissolving and recrystallization.

Grease Manufacture - This process begins with preparation of a soap base from an alkali earth hydroxice and a fatty acid. This solution is then mixed with oil and special additives to form the various lubricating greases. The major equipment consists of an oil circulation heater, a high-dispersion contactor, a scraper kettle, and a grease polisher. Because of developments in sealed grease fittings and longer lasting greases, grease production is expected to decline.

Lube Oil Finishing - This process is used in further refinement of solvent-refined and dewaxed lube oil stocks, and involves clay or acid treatment to remove color-reforming and other undesirable materials. The two methods most widely used by industry are (1) continuous contact filtration in which an oil-clay slurry is heated and the oil removed by vacuum filtration; and (2) percolation filtration, in which the oil is filtered through clay beds. Percolation also involves naphtha washing and kiln-burning of spent clay to remove carbon deposits and other impurities.

Blending and Packaging - Blending is the final step in the production of finished petroleum products to meet quality specifications and market demands. The largest volume operation is the blending of various gasoline stocks, including alkylates and other high-octane components, with anti-knock such as tetraethyl lead, anti-rust, anti-icing, and other additives. Diesel fuels, lube oils, waxes, and asphalts are other refinery products which normally require blending of various components and/or of additives. Packaging at refineries is generally highly automated and restricted to high volume, consumer-oriented products such as motor oils.

Hydrogen Manufacture - The rapid growth of hydrotreating and hydrocracking has increased the newer refineries' demand for hydrogen to a level beyond that obtained as a by-product of reforming and other refinery processes. Hydrogen is also in demand as a feedstock for ammonia and methanol manufacture. The most widely used subprocess is steam reforming, in which desulfurized refinery gases are converted to hydrogen, carbon monoxide, and carbon dioxide in a catalytic reaction; this generally requires the use of an additional shift converter to convert carbon monoxide to carbon dioxide.

Gas Recovery and Treatment - In the refining process some gases are produced that cannot be completely condensed and recovered where they originate. Therefore, gas recovery and treatment facilities are provided. Examples of such gases are hydrogen, hydrogen sulfide, methane, ethane, and propane. In the compression-recovery process, the gas is alternately pressurized and cooled to extract raw distillate. The remaining non-condensable gas is routed to a high-pressure absorber utilizing a lean oil in an absorption column. The residual gases from the absorber, usually propane, are rejected to normal refinery fuel. The bottom, or "rich" oils, from the absorber are stripped, and the recovered gases and lean oil are recycled.

2.1.3 Industry Growth and Employment

In the year 1918, immediately following World War I, there were a total of 267 refineries in the United States with a total crude oil processing capacity of approximately 1.2 million barrels per day. The average refinery capacity amounted to 4,500 barrels per day. The total number of operating refineries reached a peak in 1940, with 460 refineries processing a total of 4.2 million barrels per day, or an average of 9,100 barrels per day per refinery. In 1973, the number of refineries operating in the United States was 247, and their total daily processing capacity was approximately 14.5 million barrels. This represented an average daily capacity of approximately 60,000 barrels per refinery. In a period of only 55 years, the average refinery has thus reflected in excess of a thirteen-fold increase in crude capacity.

Total employment in the refining industry in the year 1973 was approximately 140,000. If all segments of the petroleum industry are included, such as crude oil and natural gas production, pipeline transportation, gas systems and service stations, total employment increases to almost 1,300,000*.

2.1.4 Industry Concentration **

The State of Texas has the greatest concentration of refineries, with 40 facilities, or 16.2% of the national total within its boundaries. California ranks second with 34 facilities, or 13.8% of the national total, and Louisiana follows with 18 refineries or 7.3% of the national total. The states of Illinois, Kansas, Oklahoma, Pennsylvania, and Wyoming each have ten or more refineries. There are nine states which have only one refinery each and fourteen states with no refineries. Refining capacity of individual states is roughly parallel to the number of facilities, with Texas, California, and Louisiana having aggregate daily capacities of 3,373, 1,810, and

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(*) Source: Independent Petroleum Association of America

(**) Source: Annual Refining Survey, Oil & Gas Journal, April 1, 1974

1,667 thousands of barrels, respectively (1974).

The heaviest concentration of refineries is found within EPA Region VI, where there are 80 facilities. EPA Regions V and IX have the next greatest number of refineries, with 37 and 35 facilities, respectively. A map showing EPA Regional boundaries and refinery concentrations within each Region appears in Figure 1.

2.1.5 Industry Capacity

Petroleum refinery processing capacities vary widely, ranging from 150 to 445,000 barrels per day. Twenty-four refineries in the United States have processing capabilities exceeding 150,000 barrels per day and these account for 43% of total U. S. processing capacity, although they represent only 9% of the total number of U. S. refineries. One-third of U. S. refineries have a capacity of less than 10,000 barrels per day, yet these refineries represent only 2.5% of the country's total processing capacity.

2.2 CHARACTERIZATION OF THE INDUSTRY ACCORDING TO PROCESSES

For purposes of this study, the petroleum refining industry is characterized according to refining processes. This characterization was developed in an effort to classify refineries according to their solid waste producing capabilities, which are closely correlated with refinery complexity. The EPA Effluent Guidelines Development Document for the Petroleum Refining Industry (4) refers to an API tentative refinery categorization as follows:

Refinery Type	Processes
A	Crude Topping
B	Topping and Cracking
C	Topping, Cracking, and Petrochemicals
D	Topping, Cracking and Lube Oil Proc.
E	Topping, Cracking, Lube Oil Proc. and Petrochemicals

This API categorization, based on ascending process complexity, provided a basis for subsequent characterization according to process waste emission. We found that some modification was required to more accurately reflect refinery waste distribution.

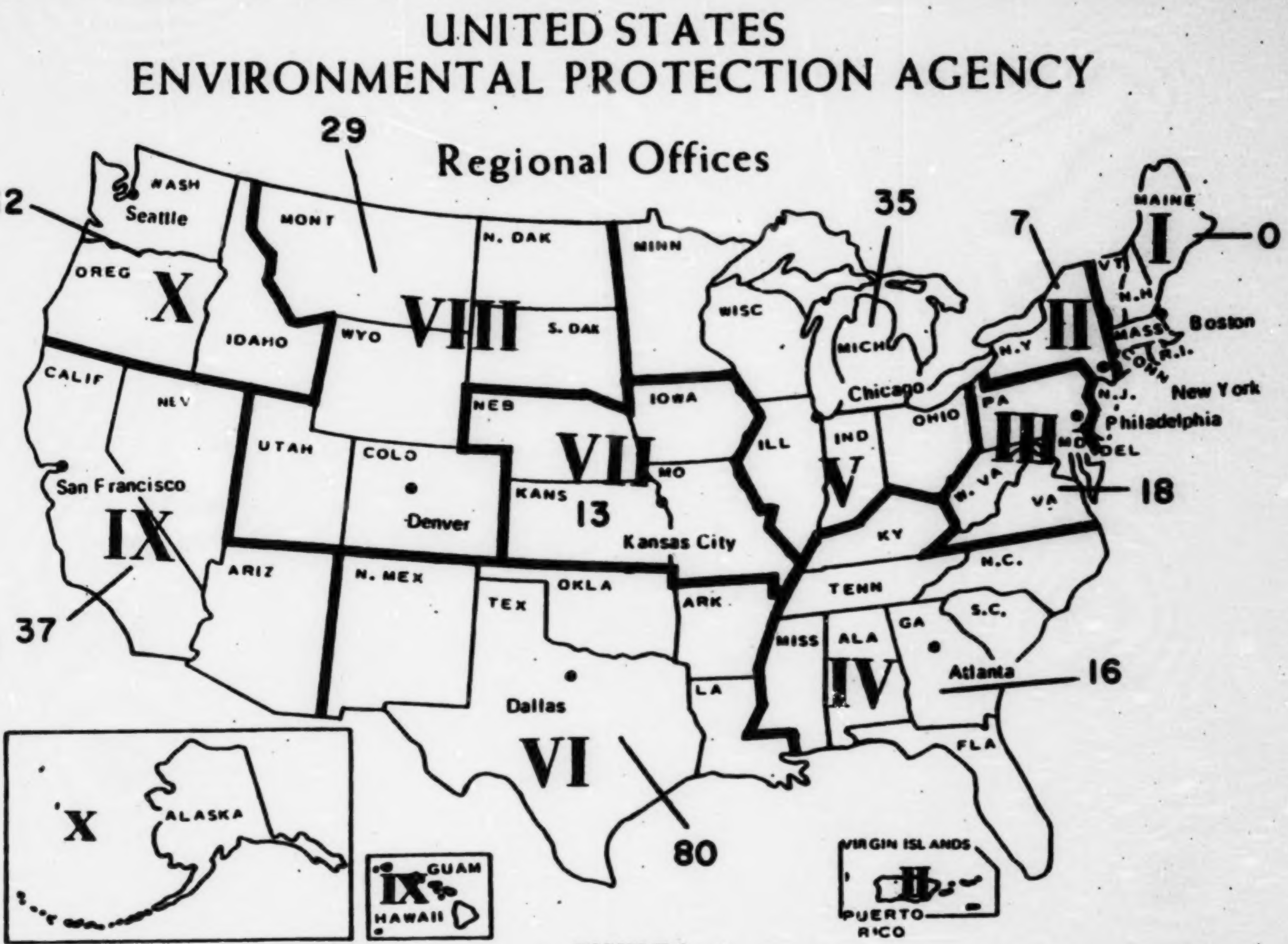
UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
Regional Offices
12
29
35
7
0
18
13
37
16
80
I
II
III
IV
V
VI
VII
VIII
IX
X
MAINE
VT
N.H
MASS
R.I.
CONN
N.Y
N.J.
PA
MD
DEL
W. VA
VA
OHIO
MICH
IND
ILL
WISC
MINN
IOWA
MO
KY
TENN
N.C.
S.C.
GA
ALA
MISS
FLA
ARK
LA
OKLA
TEX
KANS
NEB
S. DAK
N. DAK
MONT
WYO
COLO
N. MEX
UTAH
ARIZ
NEV
IDAHO
CALIF
OREG
WASH
ALASKA
GUAM
HAWAII
VIRGIN ISLANDS
PUERTO RICO
Seattle
San Francisco
Denver
Kansas City
Dallas
Chicago
Atlanta
Philadelphia
New York
Boston

FIGURE 1
REFINERY CONCENTRATION WITHIN EPA
REGIONAL BOUNDARIES
(Arabic numbers indicate number of refineries in each Region.)

Refinery process solid wastes can be generally divided into two types. Intermittent process wastes are those which generally result from the cleaning of refinery facilities and which require disposal at intervals greater than two weeks. Typical examples of these wastes are (a) storage tank bottoms, leaded and unleaded; (b) process vessel sludges, vessel scales, and deposits generally removed during plant turn-arounds; and (c) product treatment facilities wastes, such as spent filter clays, spent catalyst from units such as blender, treater, etc. Continuous process wastes result from wastewater treatment processes and from manufacturing process units, and require disposal at intervals of less than two weeks. Typical examples of wastewater treatment wastes are (a) waste biosludge, (b) dissolved air floation float, (c) centrifuge cake, and (d) vacuum filter cake. Typical of manufacturing process unit wastes are (a) spent catalysts and catalyst fines from the fluid catcracking unit; (b) coker wastes, such as coke fines from the delayed or fluidized coker, and spilled coke from the unloading facilities; and (c) spent and spilled grease and wax from the lube oil processing plants. Intermittent wastes are a function of refinery size and refinery diligence in maintenance and housekeeping practices. Continuous wastes appear to be a function of refinery wastewater treatment system complexity and of refining process unit structure.

Over all, the influence of the process appeared most important. Consequently, a process-oriented characterization of refineries gave promise of being the most useful tool for this study. The characterization adopted is as follows:

Refinery Type	Type of Processes Included
I	Crude Vacuum distillation; LP recovery; Hydrotreating; Hydrofining; Reforming; Alkylation; Isomerization; Visbreaking.
II	All processes included in Type I in addition to fluid catcracking and hydroflowing.
III	All processes included in Type II in addition to fluid or delayed coking.
IV	All processes included in Type III in addition to lube oil and petrochemical operations.

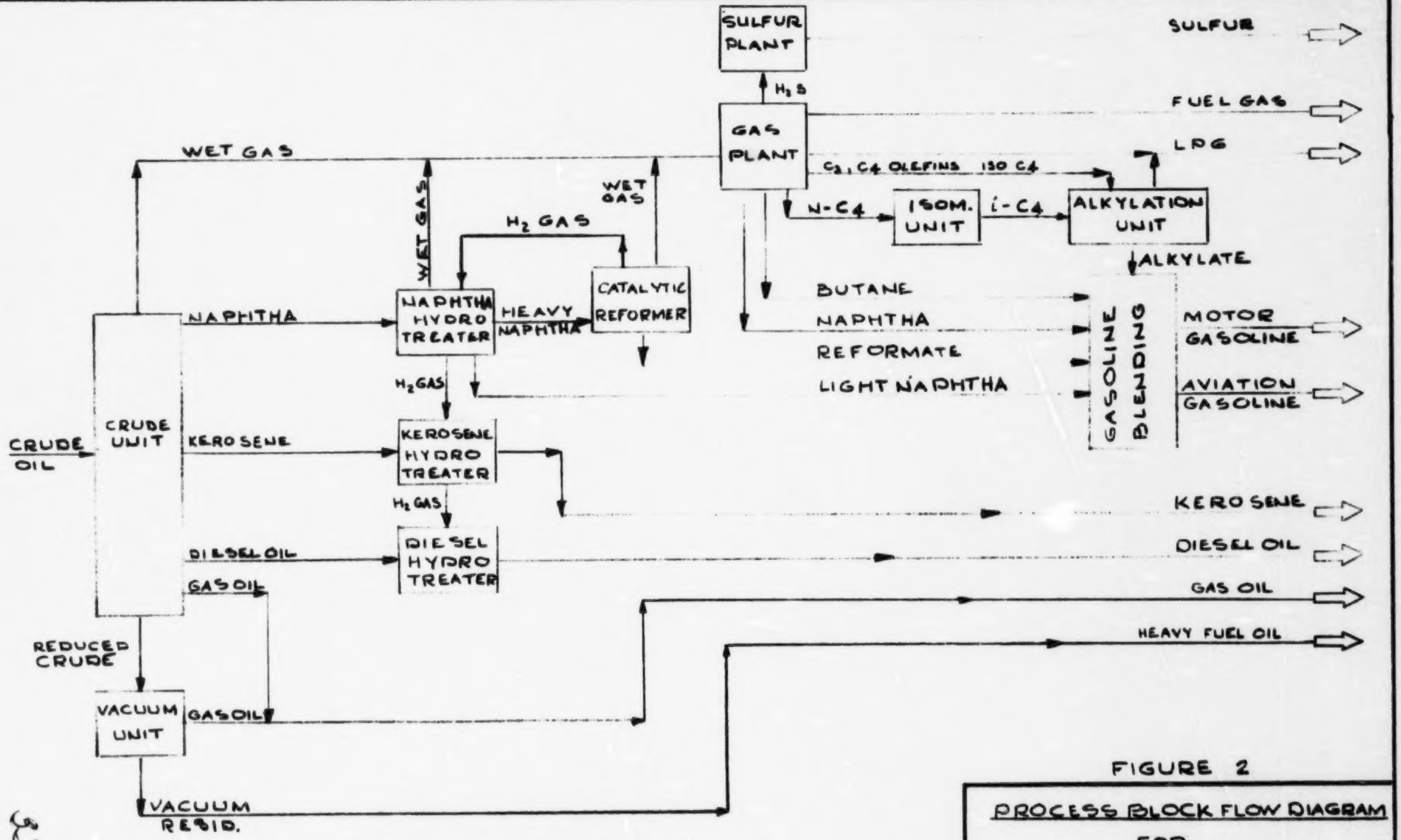
SULFUR PLANT
H₂S
GAS PLANT
SULFUR
FUEL GAS
LPG
WET GAS
WET GAS
WET GAS
H₂ GAS
C₃, C₄ OLEFINS ISO C₄
N-C₄
ISOM. UNIT
i-C₄
ALKYLATION UNIT
ALKYLATE
CATALYTIC REFORMER
NAPHTHA HYDRO TREATER
HEAVY NAPHTHA
CRUDE OIL
CRUDE UNIT
NAPHTHA
KEROSENE
DIESEL OIL
GAS OIL
BUTANE
NAPHTHA
REFORMATE
LIGHT NAPHTHA
GASOLINE BLENDING
MOTOR GASOLINE
AVIATION GASOLINE
H₂ GAS
KEROSENE HYDRO TREATER
H₂ GAS
DIESEL HYDRO TREATER
KEROSENE
DIESEL OIL
GAS OIL
HEAVY FUEL OIL
REDUCED CRUDE
VACUUM UNIT
GAS OIL
VACUUM RESID.

FIGURE 2

PROCESS BLOCK FLOW DIAGRAM
FOR
TYPICAL REFINERY IN CATEGORY I

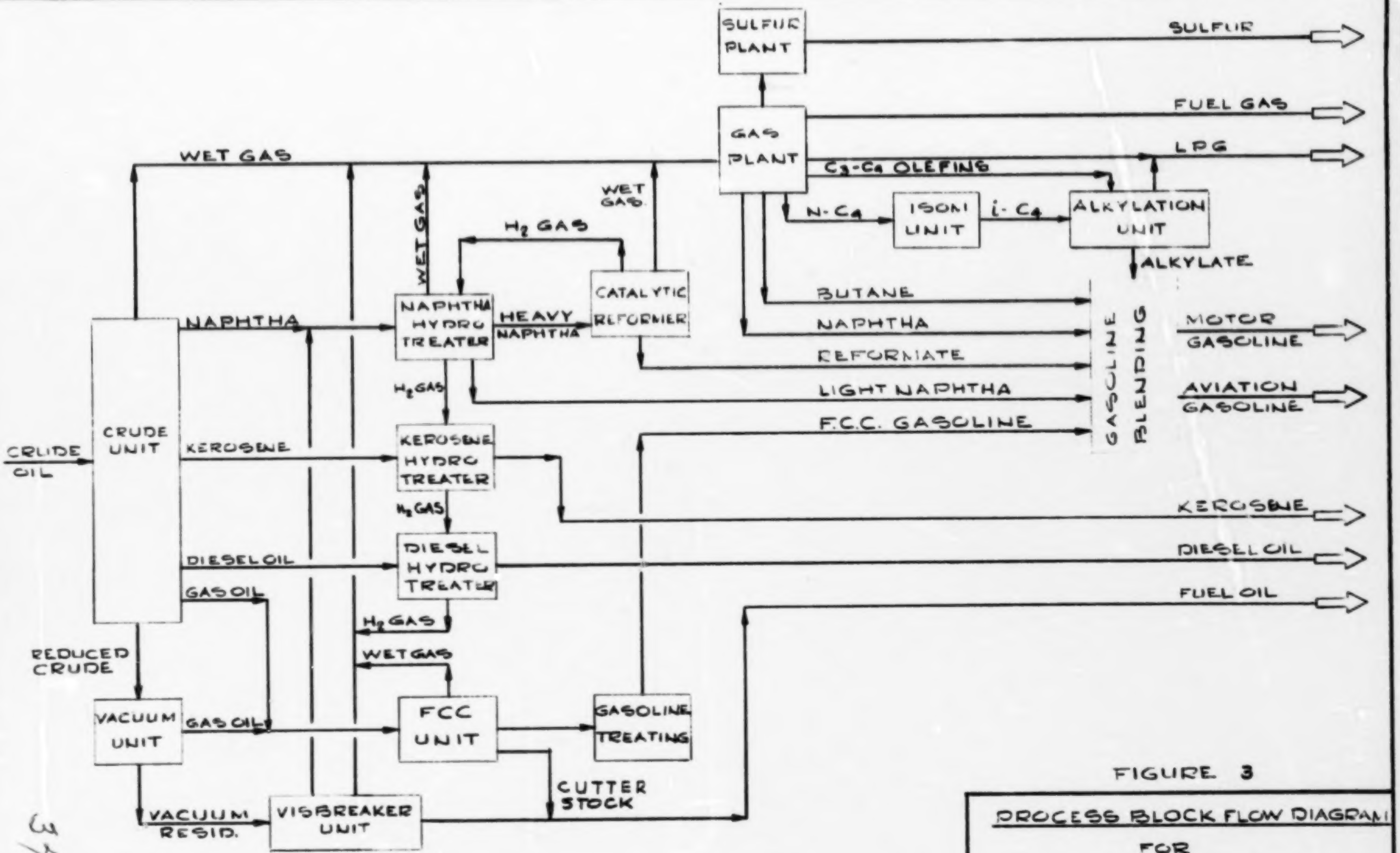
SULFUR PLANT
GAS PLANT
SULFUR
FUEL GAS
LPG
C_3-C_4 OLEFINS
N-C_4
ISOM UNIT
i-C_4
ALKYLATION UNIT
ALKYLATE
WET GAS
WET GAS
WET GAS
H_2 GAS
CATALYTIC REFORMER
NAPHTHA HYDRO TREATER
HEAVY NAPHTHA
CRUDE OIL
CRUDE UNIT
NAPHTHA
KEROSENE
DIESEL OIL
GAS OIL
BUTANE
NAPHTHA
REFORMATE
LIGHT NAPHTHA
F.C.C. GASOLINE
GASOLINE BLENDING
MOTOR GASOLINE
AVIATION GASOLINE
H_2 GAS
KEROSENE HYDRO TREATER
H_2 GAS
DIESEL HYDRO TREATER
KEROSENE
DIESEL OIL
FUEL OIL
H_2 GAS
WET GAS
REDUCED CRUDE
VACUUM UNIT
GAS OIL
FCC UNIT
GASOLINE TREATING
CUTTER STOCK
VACUUM RESID.
VISBREAKER UNIT

FIGURE 3

PROCESS BLOCK FLOW DIAGRAM
FOR
TYPICAL REFINERY IN CATEGORY II

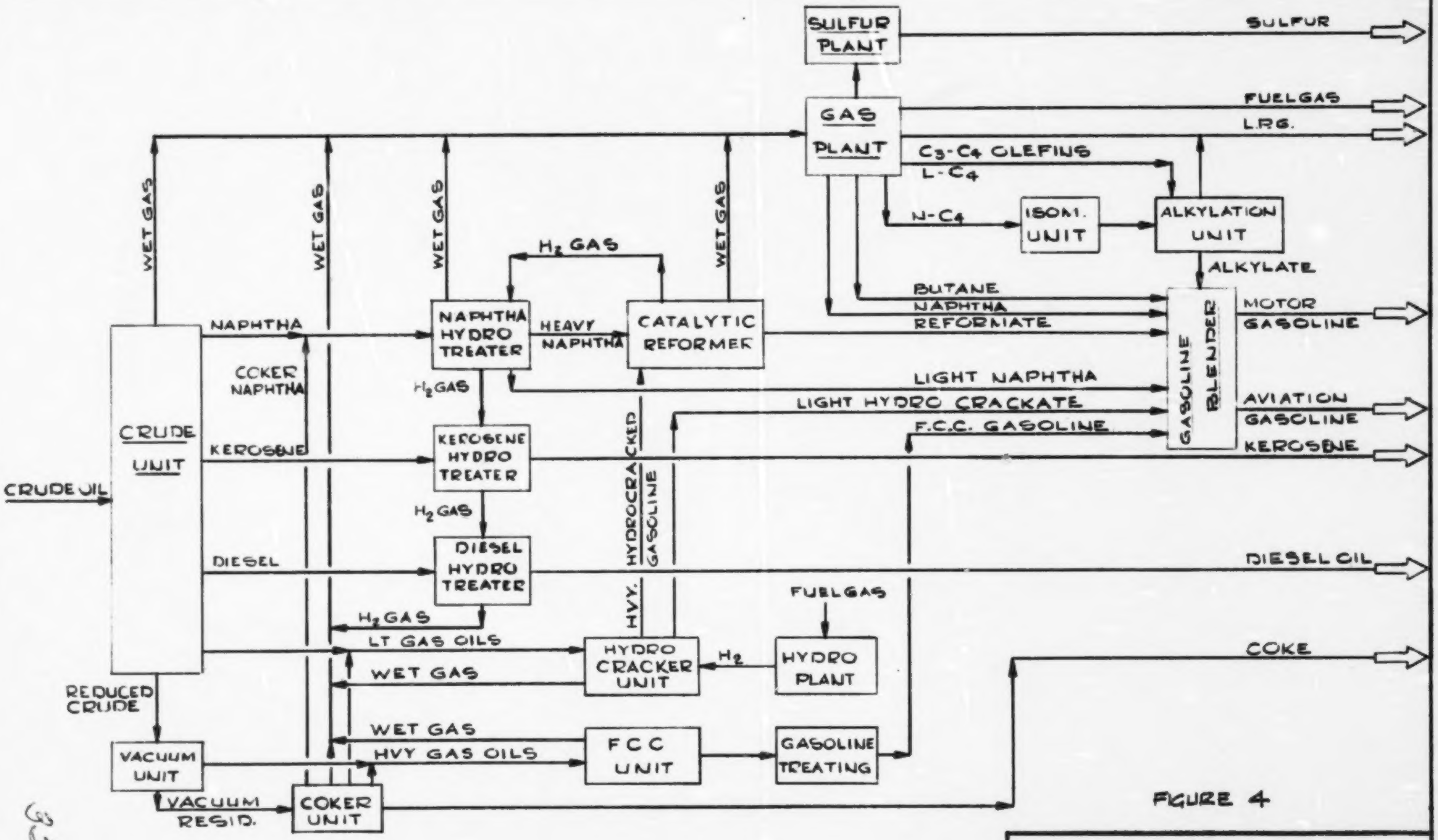
SULFUR PLANT
SULFUR
GAS PLANT
FUELGAS
L.P.G.
C3-C4 OLEFINS
L-C4
N-C4
ISOM. UNIT
ALKYLATION UNIT
ALKYLATE
BUTANE
NAPHTHA
REFORMATE
GASOLINE BLENDER
MOTOR GASOLINE
AVIATION GASOLINE
KEROSENE
LIGHT NAPHTHA
LIGHT HYDRO CRACKATE
F.C.C. GASOLINE
WET GAS
WET GAS
WET GAS
WET GAS
H2 GAS
NAPHTHA HYDRO TREATER
HEAVY NAPHTHA
CATALYTIC REFORMER
CRUDE OIL
CRUDE UNIT
NAPHTHA
COKER NAPHTHA
KEROSENE
KEROSENE HYDRO TREATER
H2 GAS
H2 GAS
DIESEL
DIESEL HYDRO TREATER
DIESEL OIL
HVY. HYDROCRACKED GASOLINE
FUELGAS
H2 GAS
LT GAS OILS
HYDRO CRACKER UNIT
H2
HYDRO PLANT
WET GAS
REDUCED CRUDE
WET GAS
HVY GAS OILS
FCC UNIT
GASOLINE TREATING
VACUUM UNIT
VACUUM RESID.
COKER UNIT
COKE

FIGURE 4

PROCESS BLOCK FLOW DIAGRAM
FOR
TYPICAL REFINERY IN CATEGORY III

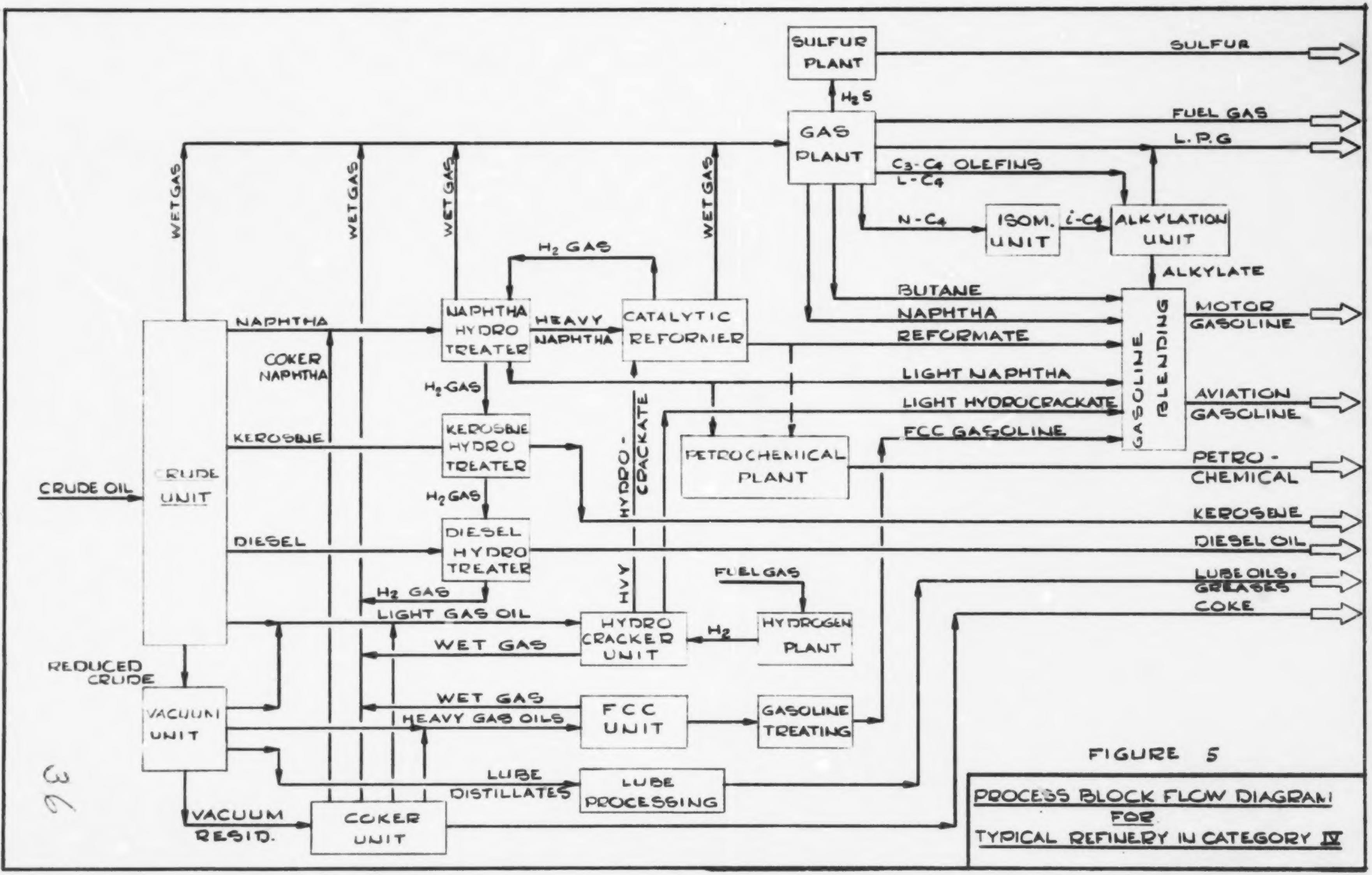
SULFUR PLANT
SULFUR
H_2S
GAS PLANT
FUEL GAS
L.P.G
C_3-C_4 OLEFINS
L-C_4
N-C_4
ISOM. UNIT
i-C_4
ALKYLATION UNIT
ALKYLATE
BUTANE
NAPHTHA
REFORMATE
LIGHT NAPHTHA
LIGHT HYDROCRACKATE
FCC GASOLINE
GASOLINE BLENDING
MOTOR GASOLINE
AVIATION GASOLINE
PETRO-CHEMICAL
KEROSENE
DIESEL OIL
LUBE OILS, GREASES
COKE
WET GAS
WET GAS
WET GAS
WET GAS
H_2 GAS
NAPHTHA
COKER NAPHTHA
NAPHTHA HYDRO TREATER
HEAVY NAPHTHA
CATALYTIC REFORMER
H_2-GAS
KEROSENE
KEROSENE HYDRO TREATER
PETROCHEMICAL PLANT
CRUDE OIL
CRUDE UNIT
H_2 GAS
HYDRO-CRACKATE
DIESEL
DIESEL HYDRO TREATER
HVY
FUEL GAS
H_2 GAS
LIGHT GAS OIL
HYDRO CRACKER UNIT
H_2
HYDROGEN PLANT
WET GAS
REDUCED CRUDE
VACUUM UNIT
WET GAS
HEAVY GAS OILS
FCC UNIT
GASOLINE TREATING
LUBE DISTILLATES
LUBE PROCESSING
VACUUM RESID.
COKER UNIT

FIGURE 5

PROCESS BLOCK FLOW DIAGRAM FOR TYPICAL REFINERY IN CATEGORY IV

Flow diagrams of operations typical of each of the four refinery types are shown in Figures 2--5. Distribution of U. S. refineries according to the selected characterization is shown in the following table:

Refinery Type	No. of Ref.	% of Total No.	Capacity (MMBPD*)	% of Total Capacity
I	98	39.7	1.177	8.3
II	65	26.3	3.486	24.5
III	29	11.7	2.058	14.5
IV	55	22.3	7.500	52.7
TOTAL	247	100.0	14.221	100.0

2.3 REFINERY DISTRIBUTION

Using the established characterization of petroleum refineries according to refining processes, the distribution of U. S. refineries has been carefully surveyed, and detailed data appears in Tables 2 through 13, pp. 38 through 50. Distribution is presented as follows:

Geographically according to state and EPA Region (Tables 2 and 3, pp. 38 and 39.

By daily capacity according to state and EPA Region, using the following refinery classifications:

(1) Small - less than 5,600 cubic meters per day (less than 35,000 barrels).

(2) Medium - 5,600 to 16,000 cubic meters per day (35,000 to 100,000 barrels).

(3) Large - more than 16,000 cubic meters per day (more than 100,000 barrels).

Tables 4 and 5, pp. 40 and 41.

By employment according to state and EPA Region, using the following classification groups:

(*) Millions of barrels per day.

TABLE 2

GEOGRAPHIC DISTRIBUTION OF U. S. REFINERIES BY STATE

Region No.	STATE	REFINERY TYPE				STATE TOTAL
		I	II	III	IV	
IV	Alabama	4				4
X	Alaska	4				4
IX	Arizona	1				1
VI	Arkansas	3			1	4
IX	California	20	3	4	7	34
VIII	Colorado	1	1		1	3
I	Connecticut					0
III	Delaware				1	1
III	Dist. of Columbia					0
IV	Florida	1				1
IV	Georgia	2				2
IX	Hawaii	1	1			2
X	Idaho					0
V	Illinois	2	1	4	4	11
V	Indiana	2	3		2	7
VII	Iowa					0
VII	Kansas	2	4	3	2	11
IV	Kentucky	1	2			3
VI	Louisiana	8	2	2	6	18
I	Maine					0
III	Maryland	2				2
I	Massachusetts					0
V	Michigan	4	2			6
V	Minnesota		2	1		3
IV	Mississippi	3	1	1		5
VII	Missouri			1		1
VIII	Montana	5	1	2		8
VII	Nebraska		1			1
IX	Nevada					0
I	New Hampshire					0
II	New Jersey		4		1	5
VI	New Mexico	5	1			6
II	New York		2			2
IV	N. Carolina					0
VIII	N. Dakota	1	1			2
V	Ohio	1	3		3	7
VI	Oklahoma	3	3	2	4	12
X	Oregon	1				1
III	Pennsylvania	3	2		6	11
I	Rhode Island					0
IV	S. Carolina					0
VIII	S. Dakota					0
IV	Tennessee		1			1
VI	Texas	12	10	6	12	40
VIII	Utah	1	5			6
I	Vermont					0
III	Virginia			1		1
X	Washington	2	3	1	1	7
III	W. Virginia				3	3
V	Wisconsin		1			1
VIII	Wyoming	3	5	1	1	10
	TOTAL	98	65	29	55	247

TABLE 3

GEOGRAPHIC DISTRIBUTION OF U. S. REFINERIES BY EPA REGION

Region by EPA	REFINERY TYPE				Region Total
	I	II	III	IV	
I					0
II		6		1	7
III	5	2	1	10	18
IV	11	4	1		16
V	9	12	5	9	35
VI	31	16	10	23	80
VII	2	5	4	2	13
VIII	11	13	3	2	29
IX	22	4	4	7	37
X	7	3	1	1	12
TOTAL	98	65	29	55	247

TABLE 4

DISTRIBUTION OF U. S. REFINERIES BY DAILY CAPACITY (STATES)

Region No.	STATE	REFINERY TYPE												STATE TOTAL
		I			II			III			IV			
		1	2	3	1	2	3	1	2	3	1	2	3	
IV	Alabama	4												4
X	Alaska	3	1											4
IX	Arizona	1												1
VI	Arkansas	3										1		4
IX	California	19	1		1	1	1	1	2	1		1	6	34
VIII	Colorado	1			1						1			3
I	Connecticut													0
III	Delaware												1	1
III	Dist. of Columbia													0
IV	Florida	1												1
IV	Georgia	2												2
IX	Hawaii	1				1								2
X	Idaho													0
V	Illinois	2				1			2	2		1	3	11
V	Indiana	2			2	1							2	7
VII	Iowa													0
VII	Kansas	2			3	1		1	2			2		11
IV	Kentucky	1			1		1							3
VI	Louisiana	8				1	1		2		2		4	18
I	Maine													0
III	Maryland	2												2
I	Massachusetts													0
V	Michigan	4				2								6
V	Minnesota				1	1				1				3
IV	Mississippi	3					1	1						5
VII	Missouri									1				1
VIII	Montana	5				1			2					8
VII	Nebraska				1									1
IX	Nevada													0
I	New Hampshire													0
II	New Jersey					3	1					1		5
VI	New Mexico	5			1									6
II	New York					2								2
IV	N. Carolina													0
VIII	N. Dakota	1				1								2
V	Ohio	1				3							3	7
VI	Oklahoma	3			2	1		1	1		1	2	1	12
X	Oregon	1												1
III	Pennsylvania	2		1	1	1					4		2	11
I	Rhode Island													0
IV	S. Carolina													0
VIII	S. Dakota													0
IV	Tennessee				1									1
VI	Texas	11	1		3	7		3	1	2		3	9	40
VIII	Utah	1			3	2								6
I	Vermont													0
III	Virginia								1					1
X	Washington	2				3			1		1			7
III	W. Virginia										3			3
V	Wisconsin					1								1
VIII	Wyoming	3			4	1		1				1		10
	TOTAL	94	3	1	25	35	5	8	14	7	12	12	31	247

Key:
1. Less than 5,600 cubic meters (m^3)(35,000 bbl)
2. 5,600 - 16,000 m^3 (35,000 - 100,000 bbl)
3. More than 16,000 m^3 (100,000 bbl)

TABLE 5

DISTRIBUTION OF U. S. REFINERIES BY DAILY CAPACITY (EPA REGIONS)

REGION By EPA	REFINERY TYPE												REGION TOTAL
	I			II			III			IV			
	1	2	3	1	2	3	1	2	3	1	2	3	
I													--
II					5	1					1		7
III	4		1	1	1			1		7		3	18
IV	11			2		2	1						16
V	9			3	9			2	3		1	8	35
VI	30	1		6	9	1	4	4	2	3	6	14	80
VII	2			4	1		1	2	1		2		13
VIII	11			8	5		1	2		1	1		29
IX	21	1		1	2	1	1	2	1		1	6	37
X	6	1			3			1		1			12
Total	94	3	1	25	35	5	8	14	7	12	12	31	247

Key:
1. Less than 5, 600 cubic meters (m^3)(35, 000 bbl)
2. 5, 600 - 16, 000 m^3(35, 000 - 10, 000 bbl)
3. More than 16, 000 m^3 (100, 000 bbl)

(1) 1 to 50 employees

(2) 51 to 100 employees

(3) 101 to 500 employees

(4) 501 to 1,000 employees

Tables 6 and 7, pp. 43 and 44.

By plant age according to state and EPA Region, using the following classifications:

(1) 1 to 4 years

(2) 5 to 30 years

(3) 31 to 50 years

(4) More than 50 years

Tables 8 and 9, pp. 45 and 46.

By product slate according to state and EPA Region. (Product distribution is not given in terms of refinery type.)

Tables 10 and 11, pp. 47 and 48.

By total crude capacity according to state and EPA Region.

Tables 12 and 13, pp. 49 and 50.

TABLE 6

DISTRIBUTION OF U. S. REFINERIES BY EMPLOYMENT (STATES)

Region No.	STATE	REFINERY TYPE																				STATE TOTAL
		I					II					III					IV					
		1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
IV	Alabama	2		2																		4
X	Alaska	4																				4
IX	Arizona	1																				1
VI	Arkansas	1	2															1				4
IX	California	9	6	5					2	1		1		2	1				1	3	3	34
VIII	Colorado	1					1												1			3
I	Connecticut																					0
III	Delaware																			1		1
III	Dist. of Columbia																					0
IV	Florida		1																			1
IV	Georgia	2																				2
IX	Hawaii			1					1													2
X	Idaho																					0
V	Illinois	2							1					1	3				1	2	1	11
V	Indiana	2							3											1	1	7
VII	Iowa																					0
VII	Kansas	2							4					3					2			11
IV	Kentucky	1							1	1												3
VI	Louisiana	4	2	2					1	1				2			1	1		1	3	18
I	Maine																					0
III	Maryland		1	1																		2
I	Massachusetts																					0
V	Michigan	2	1	1					2													6
V	Minnesota								2					1								3
IV	Mississippi	1	2							1		1										5
VII	Missouri														1							1
VIII	Montana	5							1					2								8
VII	Nebraska						1															1
IX	Nevada																					0
I	New Hampshire																					0
II	New Jersey								2	1	1										1	5
VI	New Mexico	3	1	1					1													6
II	New York								2													2
IV	N. Carolina																					0
VIII	N. Dakota		1				1															2
V	Ohio		1						3											2	1	7
VI	Oklahoma	1		2				1	2					2			1		2		1	12
X	Oregon	1																				1
III	Pennsylvania	1		1		1			2									1	3	1	1	11
I	Rhode Island																					0
IV	S. Carolina																					0
VIII	S. Dakota																					0
IV	Tennessee								1													1
VI	Texas	7	4	1			1	2	6	1				6			1		1	2	8	40
VIII	Utah	1					2		3													6
I	Vermont																					0
III	Virginia													1								1
X	Washington	1	1						3					1			1					7
III	W. Virginia																	3				3
V	Wisconsin								1													1
VIII	Wyoming	3					1	1	3					1					1			10
	TOTAL	57	23	17	0	1	7	4	47	6	1	2	0	22	5	0	4	6	12	13	20	247

Key:
1. 1-50 Employees
2. 51-100 Employees
3. 101-500 Employees
4. 501-1,000 Employees
5. Over 1,000 or more Employees

TABLE 7

DISTRIBUTION OF U. S. REFINERIES BY EMPLOYMENT (EPA REGIONS)

Region by EPA	REFINERY TYPE																				Region Total
	I					II					III					IV					
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
I																					0
II								4	1	1										1	7
III	1	1	2		1			2					1				4	3	2	1	18
IV	6	3	2					2	2		1										16
V	6	2	1					12					2	3				1	5	3	35
VI	16	9	6			1	3	10	2				10			3	2	3	3	12	80
VII	2					1		4					3	1				2			13
VIII	10	1				5	1	7					3					2			29
IX	10	6	6					3	1		1		2	1				1	3	3	37
X	6	1						3					1			1					12
Total	57	23	17	0	1	7	4	47	6	1	2	0	22	5	0	4	6	12	13	20	247

Key:
1. 1-50 Employees
2. 51-100 Employees
3. 101-500 Employees
4. 501-1,000 Employees
5. Over 1,000 Employees

TABLE 8

DISTRIBUTION OF U. S. REFINERIES BY PLANT AGE (STATES)

Region No.	STATE	REFINERY TYPE																STATE TOTAL
		I				II				III				IV				
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
IV	Alabama	1	3															4
X	Alaska	2	2															4
IX	Arizona	1																1
VI	Arkansas			3												1		4
IX	California	2	15	2	1		1	1	1		3	1			2	1	4	34
VIII	Colorado		1					1							1			3
I	Connecticut																	0
III	Delaware														1			1
III	Dist. of Columbia																	0
IV	Florida		1															1
IV	Georgia		2															2
IX	Hawaii		1				1											2
X	Idaho																	0
V	Illinois		2				1				3		1	1	1	1	1	11
V	Indiana		2				1	2									2	7
VII	Iowa																	0
VII	Kansas		2				3	1			2	1			1	1		11
IV	Kentucky			1				2										3
VI	Louisiana	1	6	1			2				2			1	3	2		18
I	Maine																	0
III	Maryland		2															2
I	Massachusetts																	0
V	Michigan		2	2			2											6
V	Minnesota						1	1			1							3
IV	Mississippi		3				1				1							5
VII	Missouri											1						1
VIII	Montana		4	1			1				2							8
VII	Nebraska						1											1
IX	Nevada																	0
I	New Hampshire																	0
II	New Jersey						3		1								1	5
VI	New Mexico	1	4				1											6
II	New York						1	1			1							2
IV	N. Carolina																	0
VIII	N. Dakota		1				1											2
V	Ohio		1				2	1								1	2	7
VI	Oklahoma		3				1	1	1		1	1			1	1	2	12
X	Oregon		1															1
III	Pennsylvania		1	2				1	1							5	1	11
I	Rhode Island																	0
IV	S. Carolina																	0
VIII	S. Dakota																	0
IV	Tennessee						1											1
VI	Texas		10		2		8	2			3	3		1	4	5	2	40
VIII	Utah		1			1	4											6
I	Vermont																	0
III	Virginia										1							1
X	Washington		2				3				1				1			7
III	W. Virginia														1	1	1	3
V	Wisconsin						1											1
VIII	Wyoming		3				5					1					1	10
	TOTAL	8	75	12	3	1	46	14	4	0	20	8	1	3	16	19	17	247

Key:
1. 1-4 Years
2. 5-30 Years
3. 31-50 Years
4. Over 50 Years

TABLE 9

DISTRIBUTION OF U. S. REFINERIES BY PLANT AGE (EPA REGIONS)

Region by EPA	REFINERY TYPE																Region Total
	I				II				III				IV				
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	
I																	0
II						4	1	1								1	7
III		3	2				1	1		1				2	6	2	18
IV	1	9	1			2	2			1							16
V		7	2			8	4			4		1	1	1	2	5	35
VI	2	23	4	2		12	3	1		6	4		2	8	9	4	80
VII		2				4	1			2	2			1	1		13
VIII		10	1		1	11	1			2	1			1		1	29
IX	3	16	2	1		2	1	1		3	1			2	1	4	37
X	2	5				3				1				1			12
Total	8	75	12	3	1	46	14	4	0	20	8	1	3	16	19	17	247

Key:
1. 1-4 Years
2. 5-30 Years
3. 31-50 Years
4. Over 50 Years

TABLE 10

DISTRIBUTION OF U. S. REFINERIES BY PRODUCT SLATE (STATES)

	SIC CODE	29111-11	29111-31	29112-11	29112-13	29113-11	29114-11	29115-11	29116-11	29116-31	29117-21	29117-31	29118-13	29118-51	29118-51	29119-11	29110-21	29110-31	29110-41	29110-51	29110-61	29110-71	29110-81	29110-98
	DESCRIPTION	Aviation Gasoline	Motor Gasoline	Naphtha Jet Fuel	Kerosene Jet Fuel	Kerosene, Incl. Range Oil	Distilled Fuel Oil	Residual Fuel Oil	Liquified Refinery Gases	Other Aliphatics	Lube Oil	Lubrication Grease	Unfinished Oil	Petrochem Naphtha	Petrochem Others	Asphalt	Coke	Road Oil	Refinery Still Gases	Special Naphtha	Microcrystalline Wax	Crystalline Refined Wax	Crystalline Other	Other Finished Products
REGION NO.	STATE																							
IV	Alabama		2	3		1	4	3	1	2						3				2				
X	Alaska		1	2	2		3	3		2			2			2			2					
IX	Arizona					1	1	1								1								1
VI	Arkansas		3	1		1	5	4					1			2			1	3	1			1
IX	California	9	25	16	16	12	24	32	5	35	14	9	22	5	5	15	23	9	21	11		4	1	14
VIII	Colorado		3	1	1	2	3	2		3			2		1	1	2	1	2	1				
I	Connecticut																							
III	Delaware		1		1	1	1	1		1			1	1			1		1					1
III	Dist. of Columbia																							
IV	Florida				1		1									1								
IV	Georgia						1	2					1			2								
IX	Hawaii	1	1	1	1	1	1	1	1	1			1	1		1	1		1					
X	Idaho																							
V	Illinois	3	10	2	6	9	10	11			2	2	11	3	2	5	.9	3	9	3			1	5
V	Indiana		5	2	3	4	7	7		6	1		5	2	1	5	6	2	6	3	1	1	1	3
VII	Iowa																							
VII	Kansas	1	11	2	3	11	10	11	1	9	2		1	9	1	8	9		1	8	2		1	2
IV	Kentucky		3	1	1	3	3	3	1	1	1		2		1	2	1		2	1				2
VI	Louisiana	2	18	6	6	12	18	16	3	9	2		13	2	7	5	7		13	3	2	2	2	7
I	Maine																							
III	Maryland					1	1	1					1			2				1				
I	Massachusetts																							
V	Michigan		4	1	1	3	4	4	1	1	1		2			2	3			5	3			2
V	Minnesota		3	1	1	1	3	3	3	1			3			2	3		2					
IV	Mississippi	1	4	3	2	2	5	5		5			2		1	4	3		2	2				
VII	Missouri		1	1	1	1	1	1		1			1		1	1		1	1					
VIII	Montana	1	6	5	2	3	8	8	4	2	1		5			6	4	4	6	1				2
VII	Nebraska		1			1	1	1		1			1			1	1		1					
IX	Nevada																							
I	New Hampshire																							
II	New Jersey	2	5	1	3	4	5	5	5	5	2	1	4	1	1	2	5		5	2	1	1	1	3
VI	New Mexico		6	2	2	5	5	6	1	4			3			2	2		4					
II	New York																							
IV	N. Carolina		1			1		1					1											
VIII	N. Dakota		2	2	2	2	2	2		2			2				1		2					
V	Ohio	1	7	2	4	5	7	7	2	7	2	2	6	2		3	7		7	2			1	3
VI	Oklahoma	1	10	7	4	10	12	10	2	2	4		11	1	1	8	8	2	7	6	2	1	1	5
X	Oregon					1	1	1								1				1				
III	Pennsylvania	1	11	2	3	9	11	10	2	4	8		9			3	3		10	6	4	3	3	6
I	Rhode Island																							
IV	S. Carolina																							
VIII	S. Dakota																							
IV	Tennessee		1	1		1	1	1		1			1			1	1		1					
VI	Texas	11	40	22	20	34	40	39	23	17	8		37	19	13	16	29	3	31	22	6	5	5	19
VIII	Utah	2	6	3	4	4	6	6	4				6			2	4	1	4	2				2
I	Vermont																							
III	Virginia		1				1	1		1			1	1			1		1					
X	Washington		6	4	5	2	7	6	2	2	1	1	5	1		3	4		5	1				2
III	W. Virginia		3				3	1			3	2	2						3		1	1	2	1
V	Wisconsin		1			1	1	1		1			1			1	1		1					
VIII	Wyoming	2	10	4	4	5	9	10	4	4	1	1	6			7	9	4	6	1	1	1	1	3
	TOTAL	38	212	98	99	154	226	227	65	130	53	18	172	48	35	120	148	30	163	85	21	19	20	84

TABLE 11

DISTRIBUTION OF U. S. REFINERIES BY PRODUCT SLATE (EPA REGIONS)

SIC CODE	29111-11	29111-31	29112-11	29113-11	29113-11	29114-11	29115-11	29116-11	29116-31	29117-21	29117-31	2911[illegible]-13	29118-15	29118-51	29119-11	29110-21	29110-31	29110-41	29110-51	29110-61	29110-71	29110-81	29110-98
DESCRIPTION REGION BY EPA	Aviation Gasoline	Motor Gasoline	Naphtha Jet Fuel	Kerosene Jet Fuel	Kerosene, Incl. Range Oil	Distilled Fuel Oil	Residual Fuel Oil	Liquified Refinery Gases	Other Aliphatics	Lube Oil	Lubrication Grease	Unfinished Oil	Petrochem Naphtha	Petrochem Others	Asphalt	Coke	Road Oil	Refinery Still Gas	Special Naphtha	Microcrystalline Wax	Crystalline, Refined Wax	Crystalline, Other	Other Finished Products
I																							
II	2	6	1	3	5	5	6	5	5	2	1	5	1	1	2	5		5	2	1	1	1	3
III	1	16	2	4	11	17	14	2	6	11	2	14	2		5	5		15	7	5	4	5	8
IV	1	10	8	4	7	15	14	2	9	1		5	0	2	13	5		5	5	0	0	0	2
V	4	30	8	15	23	32	33	6	16	6	4	29	7	4	18	29	5	30	11	1	1	3	13
VI	14	77	38	32	62	80	75	29	32	14	0	65	22	21	33	46	5	56	34	11	8	8	32
VII	1	13	3	4	13	12	13		11	2	0	3	9	1	10	10		3	8	2	0	1	2
VIII	5	27	15	13	16	28	28	12	11	2	1	21	0	1	16	20	10	20	5	1	1	1	7
IX	10	26	17	17	14	26	34	6	36	14	9	23	6	5	17	24	9	22	11		4	1	15
X		7	6	7	3	11	10	3	4	1	1	7	1		6	4		7	2				2
TOTAL	38	212	98	99	154	226	227	65	130	53	18	172	48	35	120	148	30	163	85	21	19	20	84

TABLE 12

DISTRIBUTION OF U. S. REFINERIES BY TOTAL CRUDE CAPACITY (STATES)

	STATE	REFINERY TYPE				TOTAL
		I	II	III	IV	
IV	Alabama	5.6 (35)				5.6 (35)
X	Alaska	10.5 (66.0)				10.5 (66)
IX	Arizona	1.5 (9.0)				1.5 (9)
VI	Arkansas	2.0 (12)			7.0(44)	9.0 (56)
IX	California	49.0 (308)	30.0 (188)	50.0 (312)	159.0(1002)	288.0 (1810)
VIII	Colorado	1.4 (9)	2.8 (17)		4.8 (30)	9.0 (56)
I	Connecticut					
III	Delaware				22.0(140)	22.0 (140)
III	Dist. of Columbia					
IV	Florida	0.8 (5)				0.8 (5)
IV	Georgia	2.3 (15)				2.3 (15)
IX	Hawaii	4.8 (30)	6.4 (40)			11.2 (70)
X	Idaho					
V	Illinois	0.4 (3)	13.4 (84)	76.0 (478)	93.3 (587)	183.1 (1152)
V	Indiana	3.0 (19)	14.6 (92)		70.1 (441)	87.7 (552)
VII	Iowa					
VII	Kansas	1.3 (8)	19.1 (120)	24.6 (154)	19.1 (120)	64.1 (402)
IV	Kentucky	0.5 (3)	25.0 (157)			25.5 (160)
VI	Louisiana	17.4 (109)	37.0 (233)	28.6 (180)	181.48 (1135)	264.5 (1657)
I	Maine					
III	Maryland	3.7 (24)				3.7 (24)
I	Massachusetts					
V	Michigan	6.2 (39)	15.7 (99)			21.9 (138)
V	Minnesota		13.3 (84)	17.0(107)		30.3 (191)
IV	Mississippi	3.4 (21)	38.2 (240)	4.5 (29)		46.1 (290)
VII	Missouri			16.8 (105)		16.8 (105)
VIII	Montana	3.0 (19)	6.7 (42)	15.5 (98)		25.2 (159)
VII	Nebraska		0.8 (5)			0.8 (5)
IX	Nevada					
I	New Hampshire					
II	New Jersey		82.8 (521)		15.6 (98)	98.4 (619)
VI	New Mexico	5.5 (34)	3.3 (21)			8.8 (55)
II	New York		17.1 (108)			17.1 (108)
IV	N. Carolina					
VIII	N. Dakota	0.8 (5)	7.6 (48)			8.4 (53)
V	Ohio	1.6 (10)	24.3 (153)		65.2 (410)	91.1 (573)
VI	Oklahoma	9.5 (60)	14.9 (94)	10.7 (68)	41.4 (261)	76.5 (483)
X	Oregon	2.2 (14)				2.2 (14)
III	Pennsylvania	30.7 (193)	6.1 (38)		73.2 (458)	110.0 (689)
I	Rhode Island					
IV	S. Carolina					
VIII	S. Dakota					
IV	Tennessee		4.6 (29)			4.6 (29)
VI	Texas	17.7 (112)	90.0 (566)	56.8 (357)	429.2 (2700)	593.7 (3735)
VIII	Utah	0.8 (5)	20.6 (130)			21.4 (135)
I	Vermont					
III	Virginia			8.4 (53)		8.4 (53)
X	Washington	1.3 (8)	36.8 (232)	15.3 (96)	0.8 (5)	54.2 (341)
III	W. Virginia				3.1 (20)	3.1 (20)
V	Wisconsin		5.9 (37)			5.9 (37)
VIII	Wyoming	0.2 (2)	17.2 (108)	3.4 (21)	6.8 (43)	27.6 (174)
	TOTAL	187.1 (1,177)	554.2 (3,486)	327.6 (2,058)	1192.1 (7,494)	2261 (14,215)

Capacity Unit: 1,000 cubic meters (m^3/day)

1,000 barrels/day

TABLE 13

DISTRIBUTION OF U. S. REFINERIES BY TOTAL CRUDE CAPACITY (EPA REGIONS)

Region by EPA	REFINERY TYPE				Region Total
	I	II	III	IV	
I					
II		99.9 (629)		15.6 (98)	115.5 (727)
III	34.4 (217)	6.1 (38)	8.4 (53)	98.3 (618)	147.2 (926)
IV	12.6 (79)	67.8 (426)	4.5 (29)		84.9 (534)
V	11.2 (71)	87.2 (549)	93.0 (585)	228.6 (1438)	420.0 (2643)
VI	52.1 (327)	145.2 (914)	96.1 (605)	659.1 (4140)	952.5 (5986)
VII	1.3 (8)	19.9 (125)	41.4 (259)	19.1 (120)	81.7 (512)
VIII	6.2 (40)	54.9 (345)	18.9 (119)	11.6 (73)	91.6 (577)
IX	55.3 (347)	36.4 (228)	50.0 (312)	159.0 (1002)	300.7 (1889)
X	14.0 (88)	36.8 (232)	15.3 (96)	0.8 (5)	66.9 (421)
Total	187.1 (1,177)	554.2 (3,486)	327.6 (2,058)	1,192.1 (7,494)	2,261 (14,215)

Note: Capacity Unit: 1,000 cubic meters (m^3)/day
1,000 barrels/day

2.4 FUTURE TRENDS IN THE PETROLEUM REFINING INDUSTRY

2.4.1 INTRODUCTION

Growth in refinery crude capacity in 1974 amounted to about 600,000 barrels per day, which is roughly comparable to the capacity gained in the previous year (5). Most of the current gains in the capacity have resulted from expansion of existing plants, since by this means the new capacity comes on stream more quickly than by developing grass-roots facilities. Shortly after the changes in U. S. petroleum import policy were announced in April 1973, a number of companies announced plans for added refining capacity totaling more than 2 million barrels per day. The number of new refineries slated for construction continued to grow, although more slowly, through the remainder of the year. Due to higher prices and resultand decreased demand for petroleum products, plans for new refinery construction were delayed or abandoned during 1974 and 1975. Furthermore, the sharp rise in new refinery construction costs as well as the reduced profit margin resulting from current higher prices, make a new refinery a less attractive investment. Construction of some of the announced refineries has begun in hopes that prices will improve.

In the past two years there has been little change in processing intensity of downstream equipment. U. S. refineries continue to be oriented toward maximum gasoline yield and minimal residual products, while the foreign centers are geared to high distillate and residual fuel oil production. As of April 1, 1974, downstream capacity of the United States refineries as a percent of crude capacity were: hydrogen processes, 40.7%; catalytic cracking, 32.5%; catalytic reforming, 23.6%; thermal processes, 10.5%; alkylation, 6%; and hydrocracking, 6% (6). Catalytic cracking, hydrocracking, and thermal processes primarily convert residual fuel oil components to gasoline and distillate components. Catalytic reforming and alkylation improve the octane quality of gasoline components.

2.4.2 Forecasting Energy Demands

The following discussion of the energy/hydrocarbon relationship as it shapes future trends in petroleum refining is based upon a report by the Pace Company of Houston, Texas (7).

Methods

The Pace approach to forecasting energy demand has been to first determine how people have used energy in the past, and to use this as a basis for projecting how they will use it in the future. The household is considered to be the fundamental consuming unit and all forecasts are made on a per household basis. Using this technique, a forecast of transportation needs embodies the following information: (1) forecast of total travel between and within cities, and allocation of totals among the various transportation modes, i.e., automobile, bus, air, train, etc.; (2) occupancy rates for each mode to develop vehicle miles; and (3) fuel efficiencies for individual types of vehicles and weighted averages to determine fuel consumption. Appropriate factors and corrections are applied to account for current trends and for anticipated changes.

The most difficult challenge currently facing forecasters is to assess the changes in product demands and spending patterns which will result from the recent large increases in energy costs. Future demands for virtually every product will be directly or indirectly affected, but the most basic and important is the demand for energy itself. When faced with these dramatically higher costs, the individual consumer can react by changing his consumption pattern in two basic ways: (1) curtailment of energy-consuming activities, such as cutting back travel or lowering the temperature of heated spaces; and (2) shifting of buying patterns toward more energy-efficient items, such as smaller cars and better insulated houses. The first consumption pattern change is likely to be reflected in a fairly rapid reduction in energy demand, while the effects of the second pattern change are likely to be cumulative over a long period of time. Both have been assessed and integrated into the basic forecasting technique. Quantitative determinations of energy demands with respect to price are at best difficult and imprecise, but the difficulty is compounded because significantly higher energy costs have occurred only fairly recently, i.e., late 1973, and only limited statistical data [illegible] available. They are further compounded by the Arab oil embargo during late 1973 and 1974 and by the severe economic recession resulting in part from the energy crisis. Both factors tend to make the statistics inconsistent. Reaction of consumers to the sharp increases in crude oil and energy prices is best reflected in a comparison of energy consumption and economic activity of the third quarter of 1974 with the same quarter of 1973. The third quarter of 1973 was prior to the embargo and the third quarter of 1974 was after the embargo, when consumption was not limited by shortages. Table 14 gives a comparative data on energy consumption and economic activity during these two periods. As can be seen, the third quarter 1974 records a 2.4% decrease in energy consumption from the consumption of the third quarter 1973, with a simultaneous 3.6% reduction in petroleum production. During the same period the real GNP (1958 dollars) suffered a reduction of 2.1%. For reference, the average price of crude oil in the U. S. for the two periods was: $3.60/barrel (1973) and $9.20/barrel (1974). Comparisons thus do not provide measures of consumer reaction to price alone. Recognizing these limitations, the available data are used in combination with judgement in forecasting energy demands.

Demand Projections

The relatively inflexible energy supply/demand balance of 1974 resulting from the Arab oil embargo (beginning November 1973) prompted the use of two probable economic patterns, i.e., Case I and Case II, in forecasting energy demands. Case I is the highest attainable energy consumption level consistent with world oil prices. It assumes recovery from the recession by mid-1976, as well as an absence of mandatory or punitive government controls to reduce consumption, beyond those already enacted. It reflects the rapid change in consumption that actually occurred in response to the sudden increase in prices. Case II is the current estimate of the energy consumption level which would result from de-control of U. S. crude oil prices and retention of the $3.00 per barrel oil import tariff initiated by the President. It assumes reduced consumption, particularly in the household/commercial and transportation sectors, as a result of higher energy costs.

The assessment of energy consumption corresponding with Case I economic patterns assumes that the trends which have occurred since the beginning of the sharp price escalations in late 1973, such as increased use of small cars and reduction in heating and cooling of homes, represent permanent changes rather than short-term emotional reactions. Two significant events have occurred that affect transportation energy consumption but which are not directly related to consumer reaction: (1) The addition of catalytic mufflers has resulted in a significant improvement in efficiency for 1975 model cars. Although previous forecasts had assumed further penalties as catalytic mufflers were added, EPA data show an average improvement for new cars amounting to about 15% over 1974 models. (2) Enaction by Congress of a national speed limit of 55 miles per hour has resulted

Table 14

ENERGY CONSUMPTION AND ECONOMIC ACTIVITY: THIRD QUARTER, 1973 and 1974

ENERGY CONSUMPTION	Third Quarter 1973	Third Quarter 1974	Percent Change (1974 vs. 1973)
Coal			
Million Tons	144.5	141.8	
MB/Day as COE*	6,127	6,012	-1.9
Natural Gas			
Billion Cubic Feet	5,841	5,551	
MB/Day as COE*	10,758	10,222	-5.0
Petroleum			
MB/D as COE*	15,824	15,254	-3.6
Total Energy			
MB/D as COE*	34,272	33,446	-2.4
Electric Power (Billion KWH)			
Total Generation	504.8	501.0	-0.1
Sales to Industry	175.6	178.9	+1.9
Sales to Residential/ Commercial	266.3	260.7	-2.1
ECONOMIC ACTIVITY			
GNP (Annual Rates)			
Billion Actual Dollars	1,308.9	1,416.3	+8.2
Billion 1958 Dollars	840.8	823.1	-2.1
Constant Dollars per Capita	4,033	3,918	-2.9
Personal Consumption Expenditures (Constant Dollar Basis)	-	-	-1.5

*Crude Oil Equivalent = 5.85 million BTU.

in lower gasoline consumption in intercity travel. Case I projections assume that travel within cities will remain constant at the 1973 level and that per household intercity travel will decline in 1974. Growth of each from 1974 levels is expected to occur at the following rates: 1975 to 1977, 0% per year; 1978 to 1980, 0.5% per year; and 1981 to 1985, 1.0% per year. As a point of reference, total travel per household increased at an average annual rate of 2.2% between the years of 1969 and 1973. The assumed 1974 decline in travel is based upon a 2.1% drop in gasoline consumption during the third quarter of 1974 from that of the third quarter of 1973, the reflection of an approximate 6.0% decrease in actual automobile miles driven per household during this period. In view of this, a 3.0% travel reduction may be conservative. Historical and projected intercity and intracity travel data for the years 1969 to 1985 are shown in Tables 15 and 16, respectively.

In addition to this basic assumption, the following major assumptions influenced calculations of energy demand in the transportation section for Case I:

(1) Small car sales will stabilize at the level prevailing during the first six months of 1974, about 30% of the total for the period. Since 1970, small car sales on the West Coast (Petroleum Administration for Defense (PAD) District 5 in Figure 6) have been notably higher than the national average, and are assumed to stabilize at the current level of about 48% of national totals. Table 17 shows recent and projected future automobile sales, by size, according to Case I and II consumption patterns.

(2) Speed limit reductions will be permanent. The effect of speed restrictions on automobile gasoline consumption is shown in Table 18.

(3) There will be no increase in car pooling after 1974. This is reflected in the passenger per automobile estimates shown in Table 19, showing the ratio between automobile and passenger miles traveled.

(4) Increased proportions of total travel will be via bus, train, and air, resulting in a decline in the percentage represented by automobile travel. (Tables 15 and 16 reflect these changing modes of travel.)

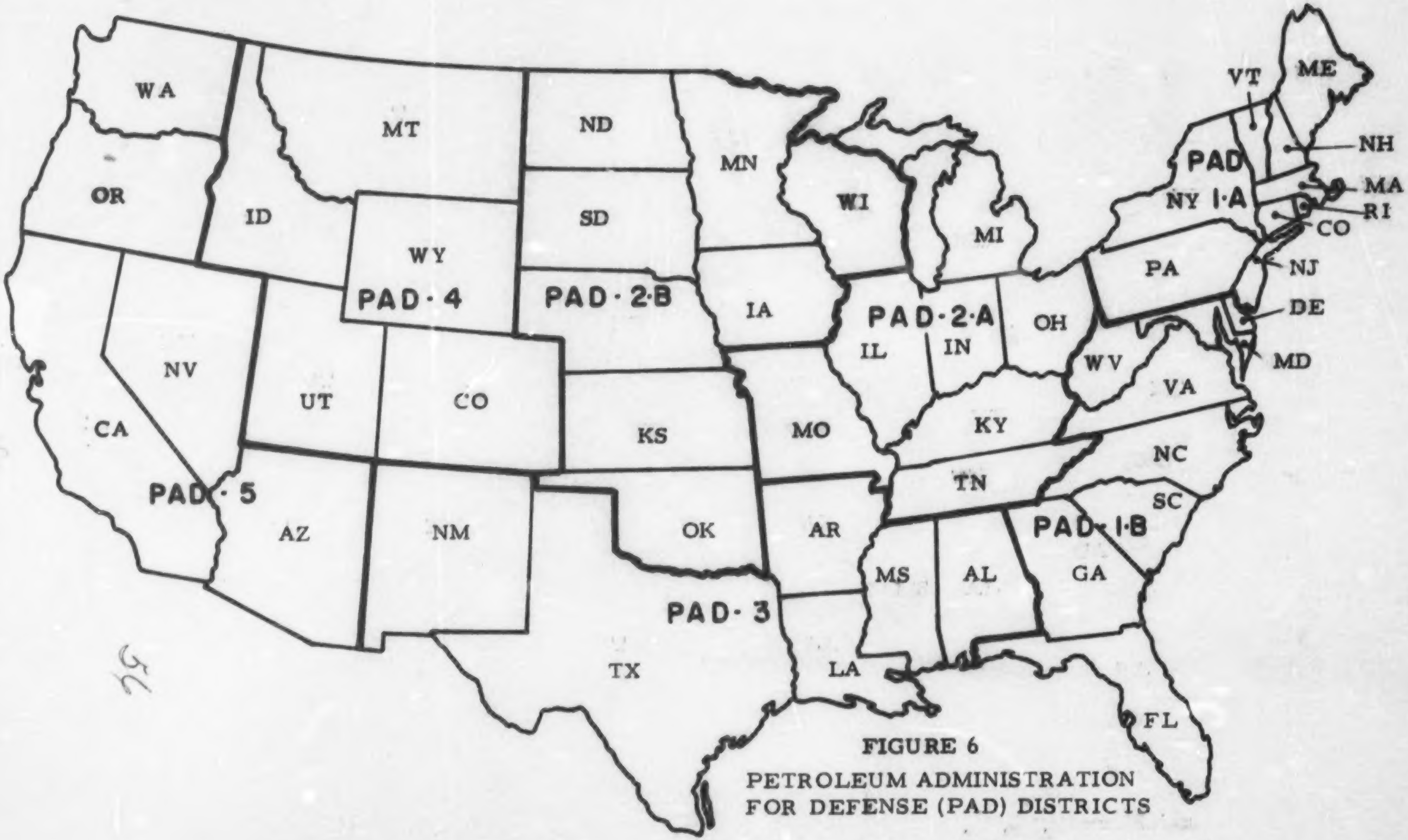
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FIGURE 6

PETROLEUM ADMINISTRATION
FOR DEFENSE (PAD) DISTRICTS

Table 15

TRAVEL BETWEEN CITIES, 1969-1985
(Case I)

	Billion Passenger Miles						Thousand Households	Miles per Household
	Automobiles	Airplanes	Buses	Railroads	Waterways	Total		
1969	977	120	25	12	3.8	1,138	62,073	18,333
1970	1,026	119	25	11	4.0	1,185	63,143	18,767
1971	1,071	120	26	9	4.1	1,230	64,293	19,131
1972	1,085	130	26	9	4.2	1,254	65,464	19,156
1973 (Est.)	1,104	135	26	11	4.3	1,280	66,656	19,203
1977	1,129	154	37	15	4	1,339	71,878	18,630
1980	1,189	172	50	19	4	1,434	75,847	18,910
1985	1,323	203	82	25	5	1,638	82,426	19,870

	Per Cent of Total					
1969	85.9	10.5	2.2	1.1	0.3	100.0
1970	86.6	10.0	2.1	1.0	0.3	100.0
1971	87.1	9.8	2.1	0.7	0.3	100.0
1972	86.5	10.4	2.1	0.7	0.3	100.0
1973 (Est.)	86.3	10.5	2.0	0.9	0.3	100.0
1977	84.3	11.5	2.8	1.1	0.3	100.0
1980	82.9	12.0	3.5	1.3	0.3	100.0
1985	80.8	12.4	5.0	1.5	0.3	100.0

TABLE 16

TRAVEL WITHIN CITIES, 1969-1985
(Case I)

	Billion Passenger Miles							
	Automobiles	Buses	Street cars	Trolley-cars	Subway/Surface Rail	Total	Thousand Households (July 1)	Miles per Household
1969	652	31	1	1	23	708	62,073	11,406
1970	692	30	1	1	21	745	63,143	11,799
1971	735	29	1	1	21	787	64,293	12,241
1972	795	28	1	1	21	846	65,464	12,923
1973 (Est.)	830	28	1	1	22	882	66,656	13,232
1977	873	44	1	1	32	951	71,878	13,230
1980	910	63	1	1	44	1,091	75,487	13,430
1985	969	116	1	1	76	1,163	82,426	14,110

	Per Cent of Total					
1969	92.1	4.4	0.1	0.1	3.3	100.0
1970	92.9	4.0	0.1	0.1	2.9	100.0
1971	93.4	3.7	0.1	0.1	2.7	100.0
1972	94.0	3.3	0.1	0.1	2.5	100.0
1973 (Est.)	94.1	3.2	0.1	0.1	2.5	100.0
1977	91.8	4.6	0.1	0.1	3.4	100.0
1980	89.3	6.2	0.1	0.1	4.3	100.0
1985	83.3	10.0	0.1	0.1	6.5	100.0

TABLE 17

NEW AUTOMOBILE SALES BY SIZE, 1970-1985
(Percent of U.S. Total)

	CASE I			CASE II		
	Small	Intermediate	Large	Small	Intermediate	Large
1970	21.8	36.4	41.8	21.8	36.4	41.8
1971	26.0	32.0	42.0	26.0	32.0	42.0
1972	25.9	33.9	40.2	25.9	33.9	40.2
1973	28.2	36.1	35.7	28.2	36.1	35.7
1974 (6 mos.)	30.1	42.4	27.5	30.1	42.4	27.5
1975	30.1	42.4	27.5	32	44	24
1977	30.1	42.4	27.5	36	42	22
1980	30.1	42.4	27.5	40	40	20
1985	30.1	42.4	27.5	40	40	20

Table 18

EFFECT OF SPEED RESTRICTIONS ON AUTOMOBILE GASOLINE CONSUMPTION, 1969-1985

Year	Factor Change Due to Speed Restrictions
1969	1.000
1972	1.000
1977	0.978
1980	0.977
1985	0.977

Notes:

The nationwide speed limit of 55 miles per hour will increase average miles per gallon for automobile journeys between cities but will not affect fuel usage within cities. The best current information is that the average fuel saving will be about 5 percent if all drivers slow down from the previous average speed of 62 miles per hour to an average of 55 miles per hour. If the average speed is less than 55 miles per hour, a greater fuel saving will be realized.

The above calculations assume a 5 percent saving on journeys between cities. The factor declines because driving between cities is expected to gain slightly within total driving.

The change is relative to fuel usage without the speed restrictions, NOT to 1969 average fuel use as in the case of the emission control penalty factors. (Table 3-7)

Table 19

RATIO OF AUTOMOBILE MILES/PASSENGER MILES FOR INTERCITY AND INTRACITY TRAVEL FOR THE YEARS 1969, 1972, 1977, 1980, AND 1985 (Case I)

	Between Cities	Within Cities	TOTAL
1969			
Billion Passenger Miles	977	652	1,629
Passengers per Automobile	2,487	1.4	--
Billion Automobile Miles	393	466	859
1972			
Billion Passenger Miles	1,085	795	1,880
Passengers per Automobile	2,489	1.4	--
Billion Automobile Miles	436	568	1,004
Projected			
1977			
Billion Passenger Miles	1,129	873	2,002
Passengers per Automobile	2.5	1.4	--
Billion Automobile Miles	452	624	1,076
1980			
Billion Passenger Miles	1,189	910	2,099
Passengers per Automobile	2.5	1.4	--
Billion Automobile Miles	476	650	1,126
1985			
Billion Passenger Miles	1,323	969	2,292
Passengers per Automobile	2.5	1.4	--
Billion Automobile Miles	529	692	1,221

Note: The automobile occupancy rate of 1.4 persons on trips within cities was determined by a survey made by the Department of Transporation. As indicated this rate has been held constant for Case I. For Case II, we have assumed that the occupancy rate for travel within cities increases to 1.6 by 1980 as a consequence of car pooling, stimulated by higher gasoline prices. The occupancy rate for between city travel has not been changed since this form of travel does not generally lend itself to car pooling.

(5) Present exhaust emission reduction schedule will be relaxed. It is assumed that beginning in 1977 (1975 in California) automobile emissions must be controlled at 2.0 grams per mile. Increases in fuel consumption resulting from use of control devices on the average automobile (exhaust emission penalty factors) are shown in Table 20.

(6) The negative effects of automobile weight and power options on gasoline mileage will continue to increase gradually, leveling off at the early 1980's (see Table 21).

(7) The seat load factor in commercial aircraft will remain at the 1974 level. Reductions in number of scheduled flights and substitution of smaller aircraft have approached a practical maximum.

Average automobile gasoline consumption associated with both case I and Case II consumption patterns is shown in Table 22. Demands for petroleum for use in all modes of travel and representing Case I and Case II consumption patterns, are given in Tables 23 and 24 respectively. Figures represent thousands of barrels per day (MBPD).

In the household/commercial sector, calculations of energy demand are based on the following major assumptions:

(1) A reduction of 1 F in spacing temperature will occur and there will be a 1 F increase in air conditioned space. Since the saving in electricity between third quarter '73 and third quarter '74 is equivalent to an increase of 2 F in the temperature of air conditioned space, the assumed 1°F change in heating and cooling may be conservative.

(2) Energy consumption for electric heating is held constant at a level of 35%.

(3) Relative amounts of gas and fuel oil used for space heating will not change from the average of the 1965 to 1970 period.

(4) Demand for space heating energy has been discounted to allow for the effect of improved insulation according to

Table 20

AUTOMOBILE EXHAUST EMISSION PENALTY FACTORS

Registration Period	CASE I	CASE II	Existing Law
1969 and Earlier(1) (Base Period)	1.00	1.00	1.00
1970 - 1974(2)	1.13	1.13	1.13
1975 - 1976(3)	1.05	1.05	1.05
1977 - 1980(4)	1.10	1.05	1.43
1981 - 1985(5)	1.05	1.00	1.37

Notes:

The penalty factor is the increase over base period fuel requirement caused by engine adjustments to conform to Federal automobile emission regulations. The increase applies only to automobiles registered after the initiation date of the regulations. The factors used derive from discussions with U.S. automobile manufacturers and government agencies concerning actual and anticipated performance.

A limit of 2 grams per mile on NO_x emissions went into effect in California in 1975. This will increase gasoline usage by about 5 percent and has been taken into account in calculating gasoline demand.

Under existing law, nationwide NO_x controls at a level of 0.4 grams per mile will go into effect in 1977. This will have a drastic effect on gasoline demand, as shown above. We have, therefore, assumed that the law will be changed to the California standard (2.0 grams/mile) in calculating Case I demand.

For Case II, we have assumed that emission control standards beyond those in effect in 1975 will not be enacted. This means that there will be no NO_x limits except those already existing in California.

(1) This was the last full year before Federal emission regulations took effect.
(2) Lower compression ratios and controls on carbon and hydrocarbon emission.
(3) Catalytic oxidation devices added.
(4) Nationwide NO_x controls scheduled.
(5) Transmission/aerodynamic/weight changes improve efficiency.

Table 21

EFFECT OF AUTOMOBILE WEIGHT AND POWER OPTIONS ON FUEL REQUIREMENT

	Factor (times 1969 base)
1969 (base year)	1.000
1972	1.037
1977	1.103
1980	1.100
1985	1.113

Notes: This factor reflects change in fuel requirement due to the added weight of various safety features (e.g. collision resistent bumpers) and the energy used by power options (mainly air conditioning). The overall factor is influenced by the size of new cars because the fractional effect is greater on a small car than on a large car. Thus an increase in small car registrations tends to increase the factor.

The change indicated above includes the effect of vehicle size, according to the schedule of new automobile registrations given in Table 3-5.

Table 22

AUTOMOBILE GASOLINE CONSUMPTION AVERAGES
(Miles per Gallon)

	Case I	Case II
1969	13.79	13.79
1970	13.83	13.83
1971	13.79	13.79
1972	13.79	13.79
1973	13.28	13.28
1974	12.76	12.76
1977	12.55	12.70
1980	12.68	13.32
1985	13.08	13.87

Table 23

TRANSPORTATION SECTOR DEMAND FOR PETROLEUM - CASE I

(MBPD)

	1970	1972	1977	1980	1985
GASOLINE					
Automobiles	4,274	4,751	5,450	5,660	5,970
Light Trucks	1,014	1,298	1,537	1,650	1,871
Heavy Trucks/Buses	314	247	137	109	95
Aviation/Non-Highway/ Losses	312	296	265	236	209
Total	5,914	6,592	7,389	7,655	8,145
DIESEL					
Heavy Trucks/Buses	373	515	771	891	1,084
Railroads	236	248	279	301	367
Bunkers/Military/ Non-Highway	256	250	313	356	414
Total	865	1,013	1,363	1,548	1,865
JET FUEL					
Commercial	666	735	756	833	940
Military	290	263	206	219	219
Total	956	998	962	1,052	1,159
RESIDUAL FUEL OIL					
Bunkers	241	209	279	308	332
Lubes	75	77	80	81	87
Military/Railroads	85	70	56	60	60
Total	401	356	415	449	479
LPG					
All Uses	87	96	63	41	22
TOTAL	8,223	9,055	10,192	10,745	11,670

Table 24

TRANSPORTATION SECTOR DEMAND FOR PETROLEUM - CASE II
(MBPD)

	1970	1972	1977	1980	1985
GASOLINE					
Automobiles	4,274	4,751	5,087	4,781	4,713
Light Trucks	1,014	1,298	1,528	1,613	1,732
Heavy Trucks/Buses	314	247	137	109	95
Aviation/Non-Highway/ Losses	312	296	261	226	197
Total	5,914	6,592	7,013	6,729	6,737
DIESEL					
Heavy Trucks/Buses	373	515	771	891	1,084
Railroads	236	248	279	301	367
Bunkers/Military/ Non-Highway	256	250	313	356	414
Total	865	1,013	1,363	1,548	1,865
JET FUEL					
Commercial	666	735	685	755	852
Military	290	263	206	219	219
Total	956	998	891	974	1,071
RESIDUAL FUEL OIL					
Bunkers	241	209	279	308	332
Lubes	75	77	80	81	87
Military/Railroads	85	70	56	60	60
Total	401	356	415	449	479
LPG					
All Uses	87	96	63	41	22
TOTAL	8,223	9,055	9,745	9,741	10,174

the following schedule:

	Percent Reduction	
	Residential	Commercial
1975 to 1977 Construction	10	15
1978 to 1981 Construction	25	25
Pre-1975 Structure in 1980	2	change
Pre-1975 Structure in 1985	4	change

The household/commercial energy demands associated with Case I consumption patterns are summarized in Table 25. Those associated with Case II consumption patterns, which assume additional reductions in energy used within the household, increased small car sales, and increased carpooling for travel within the cities, appear in Table 26.

Total U. S. energy demands corresponding to Case I and Case II, respectively, are shown in Tables 27 and 28.

2.4.3 Consumption/Production in the United States

The need to evaluate the total energy supply/demand balance led to the development by the Pace Company of a comprehensive computer model which simulates the complete energy/hydrocarbon system in seven geographical areas of the U. S. This "Energy-Hydrocarbon Model" is used to determine required new capacities, optimum locations, product slates, feedstock and energy sources for new plants, and potential shortages as well as means to offset them.

Table 29 shows the U. S. consumption and annual growth rates of major fuel products in the United States between the years 1965 and 1974, and projected consumption and growth rates associated with Case I and II consumption patterns for the years 1977, 1980, and 1985. Table 30 shows, for each demand sequence, average refinery major product slates required by the Pace energy/hydrocarbon model. These product slates are independent of imports, which are summarized in Table 31. Because of the inter-dependence of nations, there is a strong economic driving force in the energy/hydrocarbon model for balanced production slates among the United States, Europe, and other western hemisphere nations.

Table 25

HOUSEHOLD/COMMERCIAL SECTOR
ENERGY DEMAND - CASE I

THERMAL ENERGY
(Trillion BTU)

Consuming Element	1965	1970	1972	1977	1980	1985
Space Heating	8,964	10,329	10,858	12,467	12,724	13,511
Air Conditioning	103	244	316	432	525	668
Water Heating	1,469	1,691	1,763	1,934	2,045	2,230
Cooking	383	425	424	371	384	405
Refrigeration	8	4	4	3	3	3
Clothes Drying	49	70	77	126	144	171
Sub-Total	10,976	12,763	13,442	15,333	15,825	16,988
Asphalt/Road Oil	891	1,082	1,156	1,348	1,497	1,783
TOTAL	11,867	13,845	14,598	16,681	17,322	18,771

ELECTRIC POWER
(Billion KWH)

Consuming Element	1965	1970	1972	1977	1980	1985
Space Heating	25	70	113	153	192	270
Air Conditioning	78	151	187	280	312	351
Water Heating	79	97	114	136	153	179
Cooking	28	33	38	50	54	61
Refrigeration	154	200	222	244	263	298
Clothes Drying	7	19	22	28	32	38
Lighting/Small Appliances	112	191	177	281	334	420
Miscellaneous						
Sub-Total	483	761	873	1,172	1,340	1,617
Public Authority/ Street Lighting	31	49	55	75	90	115
TOTAL	514	810	928	1,247	1,430	1,732

Table 26

HOUSEHOLD/COMMERCIAL SECTOR ENERGY DEMAND - CASE II

THERMAL ENERGY (Trillion BTU)

Consuming Element	1965	1970	1972	1977	1980	1985
Space Heating	8,964	10,329	10,858	11,974	12,222	12,977
Air Conditioning	103	244	316	410	500	635
Water Heating	1,469	1,691	1,763	1,837	1,943	2,119
Cooking	383	425	424	352	364	385
Refrigeration	8	4	4	3	3	3
Clothes Drying	49	70	77	120	137	162
Sub-Total	10,976	12,763	13,442	14,696	15,169	16,281
Asphalt/Road Oil	891	1,082	1,156	1,348	1,497	1,783
TOTAL	11,867	13,845	14,598	16,044	16,666	18,064

ELECTRIC POWER (Billion KWH)

Consuming Element	1965	1970	1972	1977	1980	1985
Space Heating	25	70	113	146	184	258
Air Conditioning	78	151	187	263	293	331
Water Heating	79	97	114	129	145	170
Cooking	28	33	38	48	51	58
Refrigeration	154	200	222	244	263	298
Clothes Drying	7	19	22	27	30	36
Lighting/Small Appliances/ Miscellaneous	112	191	177	267	317	399
Sub-Total	483	761	873	1,124	1,283	1,550
Public Authority/ Street Lighting	31	49	55	75	90	115
TOTAL	514	810	928	1,199	1,373	1,665

Table 27

U.S. ENERGY DEMAND - CASE I
(Quadrillion BTU)

Sector	1965	1970	1972	1977	1980	1985
Household/Commercial	12.6	14.7	15.3	16.7	17.3	18.8
Transportation	12.7	16.5	18.0	21.2	22.4	24.2
Utility Power	10.9	16.5	18.5	25.4	29.8	36.8
Industrial				15.4	16.0	18.1
Petrochemical	17.9	20.4	20.9	3.8	4.4	5.8
Refinery Fuel & Synthetics Production				3.2	3.6	4.9
TOTAL	54.1	68.1	72.7	85.7	93.5	108.6

U.S. ENERGY DEMAND - CASE I
(Crude Oil Equivalent - MBPD

Sector	1965	1970	1972	1977	1980	1985
Household/Commercial	5,916	6,902	7,183	7,816	8,113	8,812
Transportation	5,946	7,725	8,427	9,913	10,440	11,353
Utility Power	5,096	7,715	8,650	11,881	13,956	17,222
Industrial				7,228	7,516	8,486
Petrochemical	8,383	9,554	9,788	1,777	2,067	2,702
Refinery Fuel & Synthethics Production				1,546	1,690	2,280
TOTAL	25,341	31,896	34,048	40,161	43,782	50,855

Table 28

U.S. ENERGY DEMAND - CASE II
(Quadrillion BTU)

Sector	1965	1970	1972	1977	1980	1985
Household/Commercial	12.6	14.7	15.3	16.0	16.7	18.0
Transportation	12.7	16.5	18.0	20.3	20.3	21.3
Utility Power	10.9	16.5	18.5	24.7	29.0	36.0
Industrial				15.4	16.2	18.3
Petrochemical	17.9	20.4	20.9	3.8	4.4	5.8
Refinery Fuel & Synthetics Production	____	____	____	3.2	3.4	4.4
TOTAL	54.1	68.1	72.7	83.4	90.0	103.8

U.S. ENERGY DEMAND - CASE II
(Crude Oil Equivalent - MBPD

Sector	1965	1970	1972	1977	1980	1985
Household/Commercial	5,916	6,902	7,183	7,516	7,808	8,451
Transportation	5,946	7,725	8,427	9,508	9,527	9,990
Utility Power	5,096	7,715	8,650	11,587	13,598	16,854
Industrial				7,226	7,580	8,552
Petrochemical	8,383	9,554	9,788	1,763	2,063	2,713
Refinery Fuel & Synthethics Production	_____	_____	_____	1,493	1,570	2,056
TOTAL	25,341	31,896	34,048	39,093	42,146	48,616

Table 29

U.S. CONSUMPTION AND GROWTH RATES OF MAJOR FUEL PRODUCTS, 1965-1985 (Case I and II)

	Total Gasoline		Naphtha/JP-4		Kerosene/Jet A		Diesel/No. 2 Fuel		Residual		Total Products	
	MBPD	%/Yr.	MBPD	%/Yr.	MBPD	%/Yr.	MBPD	%/Yr.	MBPD	%/Yr.	MBPD	%/Yr.
Historical												
1965	4713	0	500	0	601	0	2126	0	1608	0	9548	0
1970	5839	4.4	612	4.1	981	10.3	2540	3.6	2204	6.5	12176	5.0
1971	6063	3.8	633	3.4	992	1.1	2694	6.1	2232	1.3	12614	3.6
1972	6440	6.2	669	5.7	1041	4.9	2921	8.4	2536	13.6	13607	7.9
1974	6539	0.8	NA	0	957	-4.1	2947	0.4	2668	2.6	NA	0
Pace Projections												
High Demand Sequence (I)												
1977	7388	4.2	681	0.4	1333	11.7	3098	1.7	4864	22.2	17364	5.0
1980	7654	1.2	713	1.5	1404	1.7	3446	3.6	5978	7.1	19195	3.4
1985	8147	1.3	688	-.7	1597	2.6	4084	3.5	4944	-3.7	19460	0.3
Reduced Demand Sequence (II)												
1977	7012	2.4	668	0-	1253	9.4	3039	1.0	4359	17.8	16331	3.7
1980	6729	-1.4	690	1.1	1309	1.5	3386	3.7	5460	7.8	17574	2.5
1985	6737	0+	772	2.3	1488	2.6	3895	2.8	4770	-2.7	17662	0+

Table 30

AVERAGE REFINERY PRODUCT SLATES
(Major Products)

	Average Slates					
	1977		1980		1985	
	MBPD	%	MBPD	%	MBPD	%
High Demand Sequence(I)						
Refined Products						
Total Gasoline	6875	49.3	7515	48.0	7960	48.6
Total Naphtha	659	4.7	673	4.3	608	3.7
Kerosene/Jet A	1133	8.1	1332	8.5	1338	8.2
No. 2 Fuel/Diesel*	2801	20.1	3186	20.3	3674	22.5
Low Sulfur Residual	1749	12.5	2219	14.2	1794	11.0
High Sulfur Residual + Asphalt/Bunkers	734	5.3	739	4.7	988	6.0
Total	13951	100.0	15664	100.0	16362	100.0
Aromatics						
Benzene	80.1	38.1	87.3	29.7	121.6	29.1
Toluene	69.4	33.0	109.2	37.2	139.4	33.3
Xylenes	60.7	28.9	97.3	33.1	157.5	37.6
Total	210.2	100.0	293.8	100.0	418.5	100.0
Reduced Demand Sequence(II)						
Refined Products						
Total Gasoline	6576	48.6	6589	45.8	6552	44.9
Total Naphtha	646	4.8	672	4.7	693	4.7
Kerosene/Jet A	1033	7.6	1148	8.0	1156	7.9
No. 2 Fuel/Diesel*	2742	20.3	3126	21.7	3486	23.9
Low Sulfur Residual	1746	12.8	2116	14.7	1743	11.9
High Sulfur Residual + Asphalt/Bunkers	793	5.9	741	5.1	973	6.7
Total	13536	100.0	14392	100.0	14603	100.0
Aromatics						
Benzene	80.2	40.2	87.6	41.0	115.9	38.3
Toluene	60.7	30.4	62.8	29.5	78.5	26.0
Xylenes	58.7	29.4	62.8	29.5	108.0	35.7
Total	199.6	100.0	213.2	100.0	302.4	100.0

(*) No. 2 Fuel/Diesel does not include 0.3 wt. % Sulfur Residual.

Table 31

REFINED PRODUCT IMPORT/EXPORT SUMMARY
MBPD

To:	High Demand Case (I)									Low Demand Case (II)								
	U.S.A.			Europe			Total Exports			U.S.A.			Europe			Total Exports		
Exports From:	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985	1977	1980	1985
Europe																		
Total Gasoline	374	0	0	0	0	0	374	0	0	298	0	0	0	0	0	298	0	0
Napntha/JP-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kerosene/Jet A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel/No. 2 Fuel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Residual <1 wt. % S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1 wt. % S	626	903	932	0	0	0	626	903	932	174	809	968	0	0	0	174	809	968
Total	1000	903	932	0	0	0	1000	903	932	472	809	968	0	0	0	472	809	968
Western Hemisphere																		
Total Gasoline	100	100	100	0	0	0	100	100	100	100	100	100	0	0	0	100	100	100
Naphtha/JP-4	3	21	0	0	0	0	3	21	0	4	0	0	0	0	0	4	0	0
Kerosene/Jet A	197	53	214	0	0	0	197	53	214	214	141	287	0	0	0	214	141	287
Diesel/No. 2 Fuel	240	240	240	281	0	0	521	240	240	240	240	240	267	0	0	507	240	240
Residual <1 wt. % S	756	475	687	3	0	287	759	475	831	583	473	764	110	48	330	693	521	1094
>1 wt. % S	1000	1423	544	0	0	0	1000	1423	687	1063	1102	323	0	0	0	1063	1102	323
Total	2296	2312	1785	284	0	287	2580	2312	2072	2204	2056	1714	377	48	330	2581	2104	2044
Other World Areas																		
Total Gasoline	0	40	85	25	70	190	25	110	275	0	40	85	25	70	190	25	110	275
Naphtha/JP-4	20	20	80	105	190	405	125	210	485	20	20	80	105	190	405	125	210	485
Kerosene/Jet A	5	20	45	10	30	95	15	50	140	5	20	45	10	30	95	15	50	140
Diesel/No. 2 Fuel	5	20	170	370	440	480	375	460	650	5	20	170	370	440	480	375	460	650
Residual <1 wt. % S	0	0	0	325	305	200	325	305	200	0	0	0	325	305	200	325	305	200
>1 wt. % S	0	220	0	0	0	0	0	220	0	0	220	0	0	0	0	0	220	0
Total	30	320	380	835	1035	1370	865	1355	1750	30	320	380	835	1035	1370	865	1355	1750
Alaska & Puerto Rico																		
Total Gasoline	40	0	0	0	0	0	40	0	0	40	0	0	0	0	0	40	0	0
Naphtha/JP-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kerosene/Jet A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Diesel/No. 2 Fuel	52	0	0	0	0	0	52	0	0	52	0	0	0	0	0	52	0	0
Residual <1 wt. % S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
>1 wt. % S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	92	0	0	0	0	0	92	0	0	92	0	0	0	0	0	92	0	0
Total Imports																		
Total Gasoline	514	140	185	25	70	190	539	210	375	438	140	185	25	70	190	463	210	375
Naphtna/JP-4	23	41	80	105	190	405	128	231	485	24	20	80	105	190	405	129	210	485
Kerosene/Jet A	202	73	259	10	30	95	212	103	354	219	161	332	10	30	95	229	191	427
Diesel/No. 2 Fuel	297	260	410	651	440	480	948	700	890	297	260	410	637	440	480	934	700	890
Residual <1 wt. % S	756	475	687	328	305	487	1084	780	1174	583	473	764	435	353	530	1018	826	1294
~1 wt. % S	1626	2546	1476	0	0	0	1626	2546	1476	1237	2131	1291	0	0	0	1237	2131	1291
Total	3418	3535	3097	1119	1035	1657	4537	4570	4754	2798	3185	3062	1212	1083	1700	4010	4268	4762

2.4.4 Petroleum Demand in Other World Areas

To insure against the pitfall of "solving" energy shortages through imports, the energy balances of other world areas were evaluated, and those of Europe, Central and South America, and the Caribbean are included in the model. Respective proportions of the total energy demand which must be contributed by petroleum was determined, and the requirements of individual geographic areas for specific products was surveyed. This information is incorporated into the model, which ultimately determines the amount and location of new U. S. refining capacity consistent with U. S. energy demands, as well as the subsequent flow of petroleum products among these geographic areas.

2.4.5 New U. S. Refinery Capacity

The number and location of new refineries and expansions which have been scheduled in the United States through the year 1977 has already been announced, and Table 32 provides a listing of these additional facilities. Companies and incremental capacity are specified and locations shown by PAD districts (see Figure 6, p.56 for the years 1974 through 1977.

Table 33 shows the total new U. S. refinery capacity for the periods 1974-1977, 1978-1980, and 1981-1985, which is required to meet needs reflected in the energy/hydrocarbon model. Both regional demands and potential sources of incremental crude oil such as Alaskan North Slope crudes were influencing factors in determining locations. This required new capacity is summarized as follows:

	Case I High Demand	Case II Reduced Demand
1974-1977	1583	1576
1978-1980	1464	103
1981-1985	860	349

Figures represent thousands of barrels per day, and include additional capacity required to process Alaskan North Slope crude oil assuming decreased utilization of 3% and 6% respectively, in the high and low demand sequences, it appears that the average annual capacity additions required between the years 1978 and 1985 amount

Table 32

NEW REFINERIES AND EXPANSIONS SCHEDULED IN THE UNITED STATES BY PAD DISTRICTS

(Bbls/Day of Crude Distillation)

Company/Location	1	2A	2B/4	3	5	Total
1974						
Armco Steel (Zanesville, Ohio)		4,000				
Delta Refining Co. (Memphis, Tenn.)		14,000				
Clark (Hartford, Ill.)		45,000				
Conoco (Ponca City, Okla.)			19,000			
ORA (Phillipsburg, Kan.)			5,300			
Skelly Oil Co. (El Dorado, Kan.)			5,000			
Hunt Oil (Tuscaloosa, Ala.)				15,750		
Pride Refining (Abilene, Tex.)				15,775		
Tesoro Petroleum (Spring, Tex.)				3,500		
Farmariss (Lovington, N. Mex.)				30,000		
Caribou Four Corners (Words Cross, Utah)			2,500			
Husky (Salt Lake City, Utah)			12,000			
	-0-	63,000	43,800	65,025	-0-	171,825
1975						
BP Oil (Marcus Hook, Pa.)	45,000					
Exxon (Linden, N. J.)	30,000					
Standard of Calif. (Perth Amboy, N. J.)	80,000					
Crystal Princeton (Princeton, Ind.)		7,000				
Apco Oil Corp. (Arkansas City, Kan.)			21,000			
Kerr-McGee Corp. (Wynnewood, Okla.)			16,000			
Vickers Petroleum (Ardmore, Okla.)			28,000			
Crystal Oil Co. (Longview, Tex.)				4,500		
Exxon (Baton Rouge, La.)				14,000		
Marion Corp. (Mobile Bay, La.)				4,000		
Standard of Calif. (Pascagoula, Miss.)				40,000		
VI-Oil Company (Glenrock, Wyo.)			4,000			
Douglas Oil Co. (Paramount, Calif.)					14,000	
Kern County (Bakersfield, Calif.)					3,000	
Newhall Refining (Newhall, Calif.)					12,000	
Standard of Calif. (El Segundo, Calif.)					190,000	
Standard of Calif. (Richmond, Calif.)					175,000	
	155,000	7,000	69,000	62,500	394,000	687,500
1976						
Atlantic Richfield (Houston, Texas)				100,000		
Caribou Four Corners (Kirkland, N. M.)				800		
Champlin Petroleum (Corpus Christi, Tex.)				60,000		
Exxon (Baytown, Texas)				250,000		
Thriftway Oil Co. (Bloomfield, N. M.)				1,500		
	-0-	-0-	-0-	412,300	-0-	412,300
1977						
Texaco (Lockport, Ill.)		25,000				
Ecol, Ltd. (Garyville, La.)				200,000		
	-0-	25,000	-0-	200,000	-0-	225,000
	155,000	95,000	112,800	739,825	394,000	1,496,625

Source: "Worldwide Construction", October 7, 1974, Oil and Gas Journal, modified by Pace.

Table 33

NEW U.S. REFINERY CAPACITY OVER 1974
(MBPD)

	PADD 1	2A	3	2B/4	5	Total
High Demand Sequence (I)						
1974-1977	163	114	778	118	410	1583
1978-1980	0	484	731	12	237	1464
1981-1985	0	299	426	372	(237)	860
Sub-Total 1978-1985	0	783	1157	384	0	2324
Total	163	897	1935	502	410	3907
Low Demand Sequence (II)						
1974-1977	163	107	778	118	410	1576
1978-1980	0	103	0	0	0	103
1981-1985	27	26	0	296	0	349
Sub-Total 1978-1985	27	129	0	296	0	452
Total	190	236	778	414	410	2028

to only 282,000 barrels per day in the high demand sequence, and 53,000 barrels per day in the reduced demand sequence.

3.0 THE ANALYTICAL PROGRAM

3.1 INTRODUCTION

The purpose of the analytical program was to identify potentially hazardous constituents of refinery solid waste streams, to determine whether they are present in refinery wastes, and to measure their levels of concentration. Suitable laboratory techniques were developed, and decisions were made regarding reasonable limits of detection and required degree of analytical accuracy.

3.2 CRITERIA FOR IDENTIFICATION OF POTENTIALLY HAZARDOUS SUBSTANCES

An initial listing of potentially hazardous substances requiring identification by the analytical program was contained in the original RFP issued by the Office of Solid Waste Management Programs. The list included the following trace elements:

- Arsenic
- Beryllium
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Selenium
- Silver
- Zinc

Also listed were certain groups of organic compounds including carcinogens, pesticides, and chlorinated hydrocarbons. In-house knowledge of the petroleum refining industry prompted addition to this list of four other potentially hazardous constituents of waste, i.e., nickel, vanadium, cobalt, and molybdenum. A total of 14 trace elements, most of which had not previously been sought in refinery residues, were thus selected for identification, and for subsequent measurement of concentration levels in refinery waste streams. A discussion of the characteristics of these elements appears in Appendix A. Examination of potential chemical combinations of the selected elements to determine whether they are organic or inorganic compounds was not included in the program. Generation of this data would require separation of the samples into oil, water, and solid fractions, and the analysis of each of the three fractions separately. This would have tripled the magnitude of the program, and time limitations precluded these studies.

The identification of potentially hazardous organic compounds presented an entirely different problem. The number of potentially dangerous organic compounds is simply too great for detailed analysis. The toxic substance list (2) has over 70,000 entries, and while many are the product of a sophisticated chemical industry, there may be an equal number of naturally occurring organic compounds in petroleum and refinery wastes. The conclusion of the Booz Allen Report (1), in which this problem is reviewed, is that "oil" is potentially hazardous regardless of its individual constituents. The transient environmental damage which has resulted from oil spills lends credence to the correctness of this conclusion. It was therefore decided that oil should represent a composite of hazardous organic substances and all refinery samples were analyzed to determine their constituent percentages of oil, water, and solids. In addition to providing the quantity of oil, these data also give insight into the physical characteristics of each waste. This information is invaluable in projecting handling costs, in designing future treatment and disposal techniques, and in evaluating the adequacy of current disposal practices.

Review of various published lists of hazardous substances (2, 3) prompted our adding to the program phenolic compounds, ammonium compounds, fluorides, and strong acids and alkalis, substances which had been a focal point of many environmental concerns. The acids and alkalis were characterized by the pH of the aqueous fraction. Pesticides are not included in the program, since they are not present in petroleum and are not produced by refineries. Trace amounts of chlorinated hydrocarbons are known to be present in crude oil, however unlike DDT and its derivatives and PCB's, they are not the type that are damaging to the environment. Furthermore, they tend to be degraded in the refinery processes, particularly if the refinery has a catalytic reformer, and hence do not appear in the waste stream. Nonetheless, the first fourteen waste samples obtained were subjected to direct analysis for chlorinated hydrocarbons, using gas-liquid chromatography. Identifiable chlorinated compounds were not found in the samples. To verify these results, the waste streams from the chromatographs were submitted to mass spectroscopy and again the results confirmed an absence of chlorinated hydrocarbons from refinery wastes. This class of compounds was therefore eliminated from subsequent analytical considerations.

The chemical classes of nitrogenous hydrocarbons and polynuclear aromatics, commonly considered to be carcinogens, have been extensively studied because of concerns related to automobile exhaust emissions. Examinations of various studies concerned with these chemical groups (*) led to the conclusion that the nitrogen compounds in petroleum are not of the cancer-forming type, viz., the amines and nitrosamines. There is, furthermore, no evidence that the naturally occurring nitrogen compounds are transformed to carcinogens, either by combustion or by natural processes. Nitrogen compounds were therefore eliminated from further consideration. Polynuclear aromatics, on the other hand, are known to occur in crude oils at levels as high as 0.1%, although only a small fraction is carcinogenic (8). For example, 3:4 benz-A-pyrene occurs at a concentration of only 0.4 to 1.6 mg/l (9). It was decided that polynuclear aromatics should be included in the analytical program. Of the potentially hundreds of isomers, only benz-A-pyrene has been studied sufficiently to enable a creditable analysis to be performed. The analytical program, in the case of polynuclear aromatics, was therefore limited to benz-A-pyrene. It is probable that a near constant ratio exists between benz-A-pyrene and total polynuclear aromatics. If this is so, benz-A-pyrene can be used as an indicator of polynuclear aromatics and may prove valuable in establishing the relationship of this compound to the total carcinogenity of oily wastes.

3.3 ANALYTICAL PROCEDURES FOR DETECTION OF HAZARDOUS SUBSTANCES

Figure 7 is a schematic representation of the analytical program. Analytical methods employed in the program are detailed in Appendix B, and in general are standard methods recognized by the American Petroleum Institute (API), the American Water Works Association (AWAA), and the American Organization of Analytical Chemists (AOAC). Oxidation of the organic matter present without loss of the more volatile trace elements, particularly mercury and selenium, was achieved by the use of a previously unpublished method obtained through communication with an industry source (**). Slight modifications of this method produced satisfactory results (Procedure 4(a), Appendix B).

The need to establish reasonable detection limits required a judgemental decision regarding when a potentially hazardous material becomes frankly hazardous. The detection limits selected as a standard against which to measure trace element concentrations are based upon those levels

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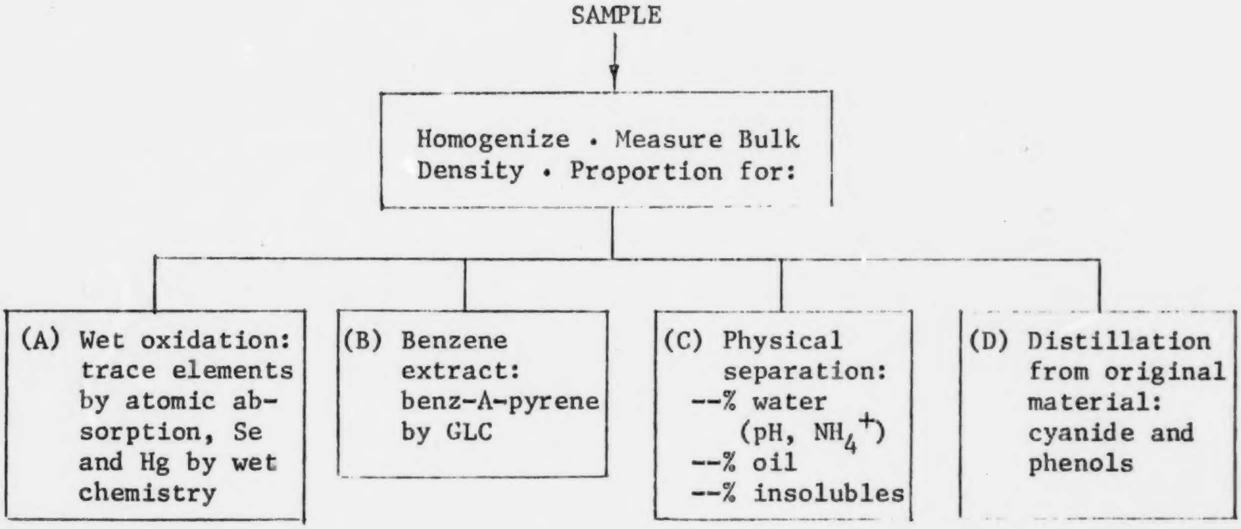
(*) Source: Chevron Research, Richmond, California; (private communication.)

(**) Source: E. N. Davis, Manager, Analytical Dept., Atlantic-Richfield Co., Harvey, Illinois.

FIGURE 7
SCHEMATIC REPRESENTATION OF THE
ANALYTICAL PROGRAM


SAMPLE
Homogenize • Measure Bulk Density • Proportion for:
(A) Wet oxidation: trace elements by atomic absorption, Se and Hg by wet chemistry
(B) Benzene extract: benz-A-pyrene by GLC
(C) Physical separation: --% water (pH, NH_4^+) --% oil --% insolubles
(D) Distillation from original material: cyanide and phenols

occurring in nature. Natural concentration levels of the collected trace elements are shown in Table 34. Since these data are somewhat variable, and there is a lack of agreement regarding precise numbers, concentrations in refinery wastes are measured against a background level equal to the average of the numbers shown in the table.

The relevance of leachate analysis to the study of potentially hazardous refining industry wastes was carefully considered, and it was concluded that such analyses are not within the scope of this study. While many individuals within the study team, as well as in the EPA and industry consider leachate analysis to be highly desirable, it was concluded that leachability of inorganic substances in standard laboratory leachate determinations is neither an accurate indicator of their solubilization potential in the biological environment, nor is it a measure of ultimate hazard. Ultimately, hazard is determined by the presence of a toxic substance, rather than by its chemical state. For example, mercury is acutely toxic if discharged to the environment in a form which can readily enter the biological environment, it is potentially chronically hazardous if disposed of as an "insoluble" inorganic compound whose entry to the life cycle can only occur after conversion to methyl mercury. Thus, if mercury did not leach into water in a standard laboratory test, it might have been concluded that mercury was bound in an insoluble form which would never leach, before discovering that several microorganisms have the ability to convert insoluble mercury to methyl mercury. The complexity of geochemical processes thus precluded leachate analysis from the analytical program.

3.4 EVALUATION OF THE ACCURACY OF LABORATORY RESULTS

Sources of error are inevitable in laboratory procedures, and are particularly apparent when determining trace quantities of toxic elements in the presence of large quantities of organic matter. The non-homogeneity of some of the samples, inherent inaccuracies associated with the methods, equipment limitations, and limitations in our knowledge introduce scatter into the results. Methods for obtaining accurate data for trace elements in organic sludges are still being improved, and when detection limits are pushed downwards, a greater degree of error often results. Determinations of the metals were made on ten gram portions, and it was generally necessary to bring the prepared solutions to 250 milliliters. Concentrations actually measured were thus about 1/25 of those reported for the original sample. Since many of the values are close to the limits of detection by standard procedures, background interference is a significant factor.

TABLE 34
CONCENTRATION LEVELS OF SELECTED TRACE ELEMENTS FOUND IN NATURE
(mg/kg dry basis)

	Av.[38]	Igneous Rocks[39]	Sed. Rocks[39]	Shales[39]	Soils[40]
Silver (Ag)	0.1	.07	.07		
Arsenic (As)	5	1.8	1	13	5
Beryllium (Be)	6	2.8	1	3	6.
Cadmium (Cd)	0.2	0.2	0.05	0.3	0.5
Cobalt (Co)	25	25	0.3	19	8
Chromium (Cr)	200	100	35	90	200
Copper (Cu)	200	55	5	45	20
Mercury (Hg)	0.1	.08	0.03	0.4	0.03
Molybdeaum (Mo)	1	1.5	0.2	2.6	2
Nickel (Ni)	80	75	2	68	4.0
Lead (Pb)	16	12.5	7	20	10
Selenium (Se)	0.5	0.05	0.05	0.6	0.01
Vanadium (V)	140	135	20	130	100
Zinc (Zn)	200	70	16	95	50
Fluorine	800	625	270	740	-

To improve interpretation accuracy, data scatter was quantified in intra-laboratory control studies. Three methods of monitoring were employed. In the first, known concentrations of trace elements were prepared in water and subjected to the same digestion and preparative procedures as refinery samples. Four groups of samples were evaluated, and the results are a measure of the error introduced by extensive pre-treatment steps required prior to actual determinations. Results are shown in Table 35 for this first series of control tests run during the program. A second method of evaluating laboratory accuracy involved the addition of known quantities of the selected elements to refinery samples. Comparison of concentration levels found with those calculated to be present in spiked original samples provided a measure of laboratory error. The third method involved performing duplicate determinations, and was carried out routinely on ten percent of these samples. Three types of samples were examined - the oily sludges, aqueous samples, and solid samples. The data obtained in the second and third series of control studies are shown in Appendix C. The data are insufficient for rigorous statistical analyses, but certain trends emerge. Inaccuracies appear to occur in the direction of lower rather than higher values, but results are accurate within the 70 to 100 percent range.

Some of the refineries analyzed identical or "split" samples, and the results provided an additional comparison standard against which to evaluate accuracy of results. Discrepancies in inter-laboratory results may reflect sampling errors as well as analytical errors, however a broad measure of agreement is found in values reported. These data are presented in Appendix D.

TABLE 35
RECOVERY OF KNOWN CONCENTRATIONS OF TRACE ELEMENTS FROM CLEAN WATER
(mg/l)

Constituent	Amount Added	Amount Recovered from Samples 1	2	3	4	Average Error
Arsenic	0.05	0.09	0.04	0.09	0.09	+0.028
Mercury	0.003	0.002	0.002	0.003	0.003	-0.0005
Beryllium	0.20	0.13	0.00	0.18	0.17	-0.080
Vanadium	4.0	2.7	3.7	3.1	4.0	-0.63
Chromium	0.80	0.77	0.25	0.57	0.70	-0.228
Cobalt	0.80	0.70	0.83	0.65	0.90	-0.030
Nickel	4.0	3.5	2.3	4.8	3.3	-0.52
Copper	0.80	0.57	0.80	0.66	0.62	-0.138
Zinc	0.40	0.35	0.29	0.54	0.34	-0.02
Silver	0.40	0.12	0.24	0.34	0.32	-0.145
Cadmium	0.40	0.36	0.35	0.40	0.40	-0.022
Lead	0.80	0.60	0.80	0.70	0.43	-0.168
Molybdenum	2.0	1.0	2.0	1.7	2.5	-0.20

4.0 WASTE CHARACTERIZATION

4.1 INTRODUCTION

This section describes the waste streams generated by the petroleum refining industry. These streams were examined to determine their composition and to measure their constituent parts. Potentially hazardous and non-hazardous constituents of refinery wastes were identified, and quantities of each were calculated for each waste stream. The results were extrapolated to the total industry for the year 1974, and are presented according to states and EPA Regions. In addition, projections are made of potentially hazardous waste generation for the years 1977 and 1983. Projected quantities are based upon changing production patterns within the industry as well as upon the effects of future air and water regulations.

4.2 WASTE GENERATION DATA DEVELOPMENT

4.2.1 Site Selection

Sixteen refineries were visited for data collection and waste sampling. Selection criteria included: (1) refinery type (representative sample from each category: see Table 36); (2) geographical location; (3) refinery age; (4) refinery size. Permission to visit these refineries was obtained with the help of the American Petroleum Institute (API) Solid Waste Task Force. In all cases, refinery personnel were most cooperative in making information available to us.

4.2.2 Data Sources

Information sheets were mailed by the API to the sixteen participating refineries in order to obtain data regarding sources of waste generation, annual waste quantities of each stream, types of discharge, i.e., continuous or intermittent, disposal methods, disposal costs, and, if possible, chemical analyses. A copy of this information sheet is found in Appendix E. Additional data were obtained during field visits, in discussions with the API Solid Waste Task Force, from information reported in the literature, and from in-house knowledge of Jacobs Engineering Co.

TABLE 36

SUMMARY OF REFINERY DISTRIBUTION
TOTAL INDUSTRY: FIELD VISITS

Refinery Category	Distribution by Number		Distribution by Capacity		Recommended Field Visit Distribution	Actual Field Visit Distribution
	Number of Refineries	Percent of Total	Capacity in (MMBPD)*	Percent of Total		
I	98	39.7	1.177	8.3	3	0
II	65	26.3	3.486	24.5	5	5
III	29	11.7	2.058	14.5	2	4
IV	55	22.3	7.500	52.7	7	7
Total	247	100	14.221	100	17	16

Note: Refinery Data Based on Oil & Gas Journal, April, 1974, Survey

*Millions of barrels per day

4. 2. 3 Refinery Field Visits

During each refinery field visit, the following procedure was utilized:

(1) The completed information sheet was reviewed by the study teams with refinery personnel.

(2) Plant operations were discussed, and information obtained concerning solid waste generation and sample collection.

(3) Generalized refinery process flow diagrams showing waste flow were sketched. These flow diagrams are included in Appendix F.

(4) A tour of the refinery was conducted to examine the various sources of solid waste and to collect samples.

4. 2. 4 Sample Collection

Both grab and composite samples were obtained. Grab samples were generally taken from intermittent waste sources and are considered appropriate since the accumulation of material over a long period of time is an effective compositing process. Composite samples taken over a period of four to five hours, were made from continuous waste sources. In the case of a pond or land disposal area, four to five grab samples were taken at various locations and then combined to form representative samples of waste sludges. Dusts and similar materials were collected in large samples (50 pounds or more), and sub-divided for analysis. In all cases, refinery personnel assisted in the sampling operation, making sure a particular process was running normally and that the waste was as representative as possible. In all cases samples were taken in a large container, thoroughly mixed, and then divided between the study team and the refinery for analysis. Sampling instructions issued to each refinery team are found in Appendix G.

4. 3 REFINERY WASTE STREAMS

Following is a listing of individual refinery waste streams with accompanying brief descriptions of their origin. A detailed characterization of each stream is given in Appendix H.

Crude Tank Bottoms - Solid sediment from incoming crude oil accumulates at the bottom of the crude oil storage tanks. These tanks are cleaned periodically to remove the sediment and the frequency is determined by the presence of sediment in the crude oil sent to the process units. In those refineries in which mixers are used in the storage tanks, this waste source is non-existent. Contaminants in crude oil tank sludge vary with type of crude oil as well as with handling and shipping methods employed prior to delivery to the refinery. Settled sludge consists of a mixture of iron,rust, clay, sand, water, sediment, and some occluded oil and wax. Usually this mixture is a tightly held emulsion which does not separate on settling. Frequency of crude oil tank sludge removal varies from once a year to once every ten years.

Leaded or Non-Leaded Tank Bottoms - Solids settle to the bottoms of product tanks, where they remain pending removal. This accumulated sludge is removed whenever the tank service is changed, the sediment exceeds specifications, or the tank itself needs repair. The characteristics of the deposited sludge will vary with the type of product stored in the tank. It is removed at intervals varying between once a year and once every five to seven years.

API Separator Sludge - Solids which settle in the API separator during primary wastewater treatment are periodically removed with a vacuum truck. Refinery API separators are usually connected to the oily water plant sewer. The bottoms, therefore, containa mixture of all sewered wastes, such as tank bottoms, boiler blow-down, and de-salter wastes, as well as a certain amount of all chemical elements that enter a refinery.

Neutralized HF Alkylation Sludge - Alkylation sludges are produced by both the sulfuric acid and the hydrofluoric acid alkylation processes. In the sulfuric acid alkylation process, the spent acid, which is approximately 80% sulfuric acid, is usually regenerated by an offsite producer of sulfuric acid, and it accumulates in storage tanks for batch transportation to the reclaimer. The sludge which contains polymerized hydrocarbons, tank scale, and sulfuric acid, accumulates on the bottom of the storage tank and is removed when the tank is either cleaned or repaired. It is usually neutralized with lime and disposed of to land. Unlike the sulfuric acid alkylation process, all spent acid from the hydrofluoric acid process is neutralized with lime (usually spent lime from the boiler feedwater treatment process) producing an insoluble calcium fluoride sludge, which is removed intermittently to final disposal.

Kerosene Filter Clays and Lube Oil Filter Clays - Treatment with fixed bed clay is used to remove color bodies, chemical treatment residues, and traces of moisture from product streams such as gasoline, kerosene, jet fuel, and light fuel oil. Clay is also used to treat lube oils, a process in which the clay is mixed with the oil and subsequently removed with a rotary vacuum filter. Since clay is used in treatment of highly refined products, the spent clay from either of the above processes is reasonably free of oil and can be disposed of in a landfill. Various clay treatment processes are discussed in Appendix H. Spent clay is produced in significantly greater quantities from the clay contacting process than from the fixed bed process.

Once-Through Cooling Water Sludge - Water pumped from a nearby source is passed through primary settling tanks prior to usage for once-through cooling. Sludge is periodically removed from these tanks.

Dissolved Air Flotation Float - In some refineries, following processing by separators, additional oil and solids are removed by the process of dissolved air flotation. The process takes place in a circular tank with or without chemicals, bringing the finely divided solids and oil particles to the surface, where they are skimmed off for disposal.

Slop Oil Emulsion Solids - Skimmed oil from the API separators is usually pumped into a slop oil tank where the mixture is separated into three fractions - oil, water and emulsion. The oil is returned for reprocessing, and the water is recycled back to the API separator. The emulsion layer may be disposed of as a sludge, or it may be further treated, i. e., demulsified. Demulsification is carried out by chemical or by physical treatment. The former employs the use of special agents, heat and settling tanks. The latter involves removal of suspended solids by centrifugation or vacuum filtration, while water and oils are effectively resolved in settling tanks. In either process, the oil is reprocessed, the water is returned to the wastewater treatment system, and the solids are disposed of as a solid waste.

Spent Lime from Boiler Feedwater Treatment - Spent lime from cold or hot lime softening and from the clarification of boiler feed water is continuously discharged, de-watered in a settling basin, and disposed of to land. The quantities and composition of the spent lime sludges are dependent upon the characteristics of the raw makeup water.

Cooling Tower Sludge - sludge which settled in the cooling tower basin is removed whenever the cooling tower is out of operation. It is either washed into the process sewer system or shoveled out and disposed of to land.

Exchanger Bundle Cleaning Sludge - Heat exchanger bundles are periodically cleaned during plant shutdown. Scale and sediment resulting from such cleaning are collected in sumps, from which they are either flushed into the process sewer system or shoveled out and disposed of to the land.

Waste Bio Sludge - In the process of biological treatment of refinery aqueous waste streams, excess bio sludge is created which, for efficient operation, must be controlled by wasting. The waste bio sludge has a very high water content (99%) and is dewatered prior to disposal. This waste is generated non-continuously at a rate dependent upon activated sludge process variations, desired level of process efficiency, and the raw waste load.

Storm Water Silt - Silt which collects in the stormwater settling basins in some refineries is periodically removed, de-watered, and disposed of to land. The quantity of silt is usually a function of the amount of rainfall and of refinery paved area, rather than of process complexity.

Fluid Catalytic Cracker (FCC) Catalyst Fines - Fluid catalytic cracker (FCC) catalyst is continuously regenerated by burning off the coke formed on the catalyst during the cracking process. The flue gas from the regenerator passes through a series of cyclones that recover most of the catalyst. This recovered catalyst is then returned to the reactor vessel. Because of current and future air pollution regulations, more refineries have installed electrostatic precipitators or an equivalent device to remove any catalyst fines which would otherwise be released to the atmosphere with the regenerator flue gas. These catalyst fines are either wasted to land or in some cases sold. They are generated on a continuous basis, but are generally disposed of intermittently.

Coke Fines - Coke which is produced in the course of various refinery operations, such as fluid coking and delayed coking, is sold as solid industrial fuel. Coke fines are generated intermittently, and their quantity is a function of handling techniques. A certain amount of spillage and consequent contamination with dirt results in the course of loading operations onto trucks and railroad cars.

Spent Catalysts - A number of refinery processes require the use of a fixed-bed catalyst. These processes include catalytic reforming, hydrodesulfurization, hydrotreating, hydrocracking, steam hydrocarbon reforming for hydrogen production, sulfur production from H_2S and/or SO_2, sulfuric acid production, and others. These catalysts eventually become inactive (viz, six months to three years) and are replaced in the reactors with fresh catalyst during a unit shutdown. Many of these catalysts contain valuable metals which can be recovered economically. Some of these metals, such as platinum and paladium, represent the active catalytic component; others are contaminants in the feed which are adsorbed on the catalyst during use. After the more valuable metals are recovered, a service performed by several companies, spent catalysts are disposed of by these companies as solid waste.

Chemical Precipitation Sludge - Chemical coagulation is used at some refineries to remove suspended matter from aqueous waste streams. The chemical coagulants which are added for this purpose form a gelatinuous, porous precipitate in which the suspended matter, both oil and solids, becomes enmeshed. The settled sludge is then removed continuously by appropriate equipment and disposed of. The composition of the sludge depends upon the type of coagulant used as well as upon the characteristics of the wastewater.

Vacuum Filter or Centrifuge Cake - In order to reduce sludge volume, some refineries concentrate certain waste streams through use of a common dewatering system. The dewatered cake from these processes is disposed of to land, while the filtrate or centrate is returned to the wastewater treatment system.

Silica Gel - Most refineries use a silica gel dessicant to remove water from the instrument air. Spent silica gel is usually disposed of to land.

4.4 FACTORS AFFECTING SOLID WASTE LOADS

Factors that affect the composition and quantity of specific solid waste streams are listed in Table 37. Some of the important factors are discussed below:

TABLE 37

FACTORS AFFECTING THE COMPOSITION AND QUANTITY OF SPECIFIC SOLID WASTE STREAMS

Waste	Factors Affecting Composition and Quantity
Crude tank bottoms	Type of crude Treatment given to crude prior to storage Slop oil processing method Refinery size Mixing, if any Storage time Degree, if any, of sludge emulsion breaking
Leaded tank bottoms	Type and quantity of chemical additives Plant and tank metallurgy Type of product treatment used Type of processes used in producing gasoline and/or other products Refinery size
Non-leaded tank bottoms	Type and quantity of chemical additives Plant and tank metallurgy Type of product treatment used Type of processes used in producing gasoline and/or other products Refinery size
API separator sludge	Composition and quantity of process wastewater Composition and quantity of spills and leaks Composition and quantities of blowdowns Refinery housekeeping Refinery size and age Segregation of refinery sewers

TABLE 37 (continued)

FACTORS AFFECTING THE COMPOSITION AND QUANTITY OF SPECIFIC SOLID WASTE STREAMS

Waste	Factors Affecting Composition and Quantity
Neutralized HF alkylation sludge	Composition of fresh HF acid Composition of lime Feedstock composition Process operating conditions HF alkylation process metallurgy Size of HF alkylation unit
Spent filter clays	Type and number of clay treating processes used Type and number of products treated Composition and quantity of products treated Type and amount of clay used Refinery size
One-through cooling water sludge	Composition and quantity of raw water Cooling system metallurgy Size and nature of process leaks Refinery size and complexity
DAF float	Same factors as API separator sludge plus: Residence time Amount and time of flocculating chemical used Efficiency of API separator
Slop oil emulsion solids	Composition and quantity of individual oil spills and oil leakages Composition of wastewater emulsions Nature of emulsion breaking treatment and degree of success Refinery size and complexity Quantity of oil in wastewater and degree of removal

TABLE 37 (continued)

FACTORS AFFECTING THE COMPOSITION AND QUANTITY OF SPECIFIC SOLID WASTE STREAMS

Waste	Factors Affecting Composition and Quantity
Spent lime from boiler feedwater treatment	Composition of raw water Degree of hardness removed Type of treatment (hot or cold) Refinery size Boiler blowdown rates Percent condensate recovered and returned to boilers
Cooling tower sludge	Make-up water composition Type of chemical treatments employed Metallurgy of cooling water system Nature of contaminants introduced by process leaks Blowdown rate Make-up water rate Quantity of treatment chemicals used
Exchanger bundle cleaning sludge	Composition of shell and tubeside fluids Equipment metallurgy Effectiveness of desalter Refinery size and complexity Effectiveness of corrosion inhibitor systems
Waste bio sludge	Composition and quantity of wastewater treated Type of biological treatment Efficiency of prior treatment units Operating conditions and practice Dewatering and/or treatment

TABLE 37 (continued)

FACTORS AFFECTING THE COMPOSITION AND QUANTITY OF SPECIFIC SOLID WASTE STREAMS

Waste	Factors Affecting Composition and Quantity
Storm water silt	Plant housekeeping Amount of rain Amount of refinery area paved Segregation of surface drainage
FCC catalyst fines	Catalyst composition Oil composition Type of process Process operating conditions (temperature, percent conversion, recycle feed rate) Catalyst make-up rate Process metallurgy Oil feed rate Number of cyclones Use of precipitators Use of elutriators
Coke fines	Oil composition Type of process Operating condition (temperature, pressure, time) Process metallurgy Method of coke removal Method of handling and shipping Number of cyclone stages Oil feed rate

Type of Crude Feed Stock - The constituents of crude oil can vary widely. The heavy metal content, for example, is of major importance in determining the hazardous or potentially hazardous metal content in crude oil storage tank bottoms, in waste FCC fines, and in the various wastewater treatment plant sludges. It is therefore reasonable to expect that solid wastes will contain different concentrations of potentially hazardous materials, and that such differences may even be reflected in the solid waste loads of two refineries of equal capacity which produce the same products but utilize different crude mixes.

Variations of Process Type - Although the petroleum industry has been divided into four categories by process type, there is variation in process units within each category. Differences in wastewater and air pollution control processes will affect the quantity as well as the composition of potentially hazardous waste material. For example, refineries which employ a hydrofluoric alkylation unit produce a sludge high in fluoride, while those employing a sulfuric acid alkylation unit do not generate large quantities of fluoride in their waste sludge. There are differences also in the degree and type of wastewater treatment processes employed by refineries. A refinery using an extended aeration sludge activation system will generate smaller quantities of biological sludges than will a refinery which uses a conventional activated sludge system. Refineries using only primary wastewater treatment before discharging into a municipal treatment system do not generate the biological sludges which are associated with secondary treatment.

Age of Processes - Process age refers to the general technology used in the process rather than to the length of time the process has been in service. This technology includes methods that will increase or decrease the quantity of solid waste. Examples of the former are air and water pollution control systems, i. e., a catalytic cracker electrostatic precipitator which increases solid waste quantity by removing particulate matter which would otherwise be an air pollutant. Examples of solid waste decreasing technology are: (a) use of air instead of water cooling, thus reducing or eliminating cooling tower sludges; (b) use of a Bender treater or hydrotreating instead of clay filters to treat kerosene; (c) use of mixers in storage tanks to prevent sludge from accumulating in the tank bottoms; and (d) processing the wastewater treatment sludges for reuse. Certain solid waste reduction processes which reduce waste mass without decreasing the quantity of potentially hazardous components are the following: (a) sludge dewatering, e. g., centrifuging or vacuum filtering; (b) digestion of waste biological sludge; and (c) reducing crude tank bottom sludges by using emulsion breakers prior to removing the sludge.

Operational Practices and Controls - Refinery operational methods have a significant impact on the final solid waste load. Among the more obvious practices which affect the quantity of solid waste are: (1) reclaiming spent catalysts for metal recovery; (2) use of filter clay not contaminated with oil for road construction; and (3) improved material-handling procedures to reduce coke fine spills. Reclaiming FCC catalyst fines is an especially important practice since these fines probably represent one of the largest single solid waste sources in a refinery with an electrostatic precipitator on the catalytic cracker. The use of corrosion inhibiters free from chromium or zinc will also affect the quantities of these potentially hazardous waste constituents generated.

4.5 DEFINITION OF POTENTIALLY HAZARDOUS WASTES

An evaluation of potentially hazardous petroleum refinery wastes to determine which among them are frankly hazardous is dependent upon a definitiion of "hazard." While a hazard is a reflection of potential damage, it can only be measured within a qualified context. For example, in relation to toxicity in ecosystems, it will vary from species to species, and from one individual member to another. Ultimately, however, a hazard to the biosphere is present if toxic substances are present, and the extent of their toxicity is directly related to their level of concentration. Concentration levels of refinery waste constituents must therefore be examined against a standard for toxicity. Because most refinery wastes are destined for land disposal, for purposes of this study the selected standard against which to measure toxicity is the average concentration of these substances which is found in the natural soil environment. Hazardous wastes are thus defined as those wastes which have at least one component with a concentration level higher than that found in the natural soil environment.

It is recognized that other definitions employing widely varying criteria may be applicable. Consideration might well be given to the use of such standards as air pollution, surface or ground water contamination, fire and explosion, or disturbances of the food chain. However, since the ultimate fate of wastes in the environment is highly complex and poorly elucidated, a more comprehensive definition would be well beyond the scope of this study. Within the framework of the definition employed in this study, waste constituents with low levels of concentration will represent a minimial hazard, regardless of the total quantity which is generated.

Conversely, although certain refinery wastes may contain a number of components with concentration levels greater than the standard, if the total quantity generated is low, the hazard will be low in spite of these levels of concentration.

4.6 HAZARDOUS WASTE STREAMS

4.6.1 Listing by Refinery Category

A listing of the types of solid wastes discharged from typical refineries in each of the four established categories is given in Table 38. It is apparent from Table 38 that similar waste streams are generated within refineries of each category. This is a direct outgrowth of the method in which the refinery categories were developed (see Section 2.2 of this report).

4.6.2 Quantification of Hazard

4.6.2.1 Measurement of Concentration Levels of Waste Stream Constituents

Analysis of each waste sample taken at the participating refineries was carried out in order to determine the concentration of each of twenty identified potentially hazardous constituent of each waste stream. These values were recorded as mg/kg, and a range of concentration levels was established. Appendix P contains a record of concentration levels found in each sample. From individual concentration ranges, median levels were determined. The median is that value which is exceeded by one-half the individual values in the series and which exceeds the remaining values. In the case of a series with an even number of values the arithmetic mean of the central pair is utilized. Table 39 lists the concentration ranges which were found, as well as median concentration values for each potentially hazardous component of all refinery waste streams. Values are expressed as milligrams per kilogram (mg/kg).

TABLE 38
TYPICAL SOLID WASTE STREAMS GENERATED BY REFINERIES OF EACH CATEGORY

Type I	Type II	Type III	Type IV
Slop oil emulsion solids	Slop oil emulsion solids	Slop oil emulsion solids	Slop oil emulsion solids
Once-through cooling water sludge	Once-through cooling water sludge	Once-through cooling water sludge	Once-through cooling water sludge
Spent lime from boiler feedwater treatment	Spent lime from boiler feedwater treatment	Spent lime from boiler feedwater treatment	Spent lime from boiler feedwater treatment
Exchanger bundle cleaning sludge	Exchanger bundle cleaning sludge	Exchanger bundle cleaning sludge	Exchanger bundle cleaning sludge
API separator sludge	API separator sludge	API separator sludge	API separator sludge
DAF	DAF	DAF	DAF
Kerosene filter clays	Kerosene filter clays	Kerosene filter clays	Kerosene filter clays
Crude tank bottoms	Crude tank bottoms	Crude tank bottoms	Crude tank bottoms
Leaded tank bottoms	Leaded tank bottoms	Leaded tank bottoms	Leaded tank bottoms
Non-leaded tank bottoms	Non-leaded tank bottoms	Non-leaded tank bottoms	Non-leaded tank bottoms
Neutralized HF alkylation sludges	Neutralized HF alkylation sludges	Neutralized HF alkylation sludges	Neutralized HF alkylation sludges
Storm water silt	Storm water silt	Storm water silt	Storm water silt
Waste bio sludge	Waste bio sludge	Waste bio sludge	Waste bio sludge
	FCC catalyst fines	FCC catalyst fines	FCC catalyst fines
		Coke fines	Coke fines
			Lube oil filter clays

TABLE 39

RANGES AND MEDIANS OF CONCENTRATIONS OF POTENTIALLY HAZARDOUS CONSTITUENTS OF REFINERY WASTE STREAMS

(Concentration levels in mg/kg (dry weight); median levels in parentheses)
(Totals in metric tons (dry weight) per 1000 BPSD of crude capacity unless otherwise noted)

Number of Samples		3	2	9	4	12	5	3	2	5
Parameters	**Typical Background ***	**Once-Through cooling water sludge**	**Exchanger bundle cleaning sludge**	**Slop oil emulsion solids**	**Cooling tower sludge**	**API/Separator Sludge**	**Dissolved Air Flotation Float**	**Kerosene Filter Clays**	**Lube Oil Filter Clays**	**Waste Biosludge**
Phenols	0.54 $^{1)}$	2.0-2.1 (2.0)	8.-18.5 (13.3)	5.7-127 (15)	0.6-7.0 (3.5)	3.8-156.7 (13.6)	3.0-210 (6.5)	2.0-25.2 (2.6)	0.05-6.4 (3.2)	1.7-10.2 (4.5)
Cyanide	2.6 $^{1)}$	0.01-0.74 (0.11)	0.0004-3.3 (1.7)	0.000012-52.5 (0.001)	0.0005-17.2 (0.1)	0.00006-51.4 (0.001)	0.01-1.1 (0.28)	0.00025-0.0007 (0.0005)	0.01-0.22 (0.12)	0001-19.5 (0.001)
Selenium (Se)	0.5	0.1-10.4 (1.6)	2.4-52 (27.2)	0.1-8.8 (1.0)	0.01-2.4 (0.015)	0.005-7.6 (0.001)	0.1-4.2 (2.0)	0.01-26.1 (9.6)	0.1-2.1 (1.1)	0.01-5.4 (0.01)
Arsenic (As)	5	0.1-18 (5.4)	10.2-11 (10.6)	2.5-18.5 (7.4)	0.7-21 (8.2)	0.1-32 (6.2)	.05-10.5 (2.0)	0.09-14 (2.2)	0.05-1.4 (0.7)	1.0-6.0 (3.8)
Mercury (Hg)	0.1	0.42-1.34 (0.51)	0.14-3.6 (1.9)	0.005-12.25 (0.59)	0.004-3.35 (0.09)	0.04-6.2 (0.4)	0.07-0.89 (0.27)	0.0004-0.05 (0.0004)	0.04-0.33 (0.19)	0.004-1.28 (0.18)
Beryllium (Be)	6	0.013-0.63 (0.24)	0.05-0.34 (0.20)	0.002-0.38 (0.0025)	0.001-0.2 (0.0013)	0.0012-0.24 (0.0025)	0.0012-0.25 (0.0025)	0.025-0.35 (0.2)	0.025-0.5 (0.26)	0.0013-.002 (0.0013)
Vanadium (V)	140	15.-57. (39.)	0.7-50 (25.)	0.12-75 (25)	0.12-35 (7.8)	1.0-48.5 (9.8)	0.05-0.15 (0.05)	13.2-42 (35)	0.5-65 (33)	.012-5.0 (.05)
Chromium (Cr)	200	16.6-103 (63)	310-311 (311)	0.1-1750 (525)	181-1750 (554)	0.1-6790 (253)	28-260 (140)	0.9-25.8 (2.88)	1.3-45 (23.2)	0.05-475 (300)
Cobalt (Co)	25	5.5-11.2 (6.3)	0.2-3.0 (1.6)	0.1-82.5 (10)	0.38-7 (1.3)	0.1-26.2 (5.7)	0.13-67.5 (2.0)	0.4-2.3 (0.62)	1.3-5. (3.2)	0.05-1.4 (0.2)
Nickel (Ni)	80	20.5-39. (35.)	61-170 (116)	7.5-160 (50)	0.25-50 (6.8)	0.25-150.4 (19.3)	0.025-15 (0.025)	0.025-15 (0.04)	0.25-22 (11.1)	0.013-11.3 (0.025)
Copper (Cu)	200	57.4-180 (153)	67-75 (71)	8.5-420 (48)	13-363 (50)	2.5-550 (18.6)	0.05-21.3 (7.0)	0.4-9,875 (11.4)	0.5-8.0 (4.3)	1.5-11.5 (9.5)
Zinc (Zn)	200	93-233 (125)	91-297 (194)	60-2725 (250)	118-1100 (675)	25-6596 (298)	10-1825 (85)	6.6-35. (25)	0.5-115. (57.6)	3.3-225 (122)
Silver (Ag)	0.1	0.24-1.3 (0.5)	0.0007-0.01 (0.005)	0.013-20.1 (0.4)	0.01-1.6 (0.28)	0.05-3 (0.45)	0.0013-2.8 (0.25)	0.02-0.7 (0.5)	0.013-1.0 (0.5)	0.1-0.5 (0.3)
Cadmium (Cd)	0.2	0.0024-1.0 (0.003)	1.0-1.5 (1.3)	0.025-2 (0.19)	0.06-0.6 (0.3)	0.024-3.0 (0.42)	0.0025-0.5 (0.005)	0.19-0.4 (0.25)	0.025-1.5 (0.76)	0.16-0.54 (0.3)
Lead (Pb)	16	17.2-138. (57.)	0.5-155 (78)	0.25-580 (28.1)	1.2-89. (38)	0.25-1290 (26)	2.3-1250 (7.5)	4.25-12 (8.3)	0.25-2.3 (1.28)	1.2-17 (5.0)
Molybdenum (Mo)	1	0.05-33 (2.5)	1-12 (6.5)	0.25-20 (5)	0.25-2.5 (1.1)	0.25-60 (5)	0.025-2.5 (0.05)	0.012-8.8 (0.025)	0.025-0.05 (0.038)	0.25-2.5 (2.5)
Ammonium Salts (as NH_4)	No Value $^{1)}$	0.1-13 (6.)	5-11 (8)	1.5-44 (8)	0.07-14 (6.3)	0.05-30 (6.5)	8.5-210 (9)	(0.01)	(2)	6.5-30 (21)
Benz-A-pyrene	<0.01 $^{1)}$	0.003-1.8 (0.004)	0.7-3.6 (2.2)	0.002-0.018 (0.003)	0.003-0.8 (0.004)	0.002-4.5 (0.004)	0.004 -1.75 (0.002)	1.7-1.8 (1.8)	0.02-0.2 (0.1)	0.002-0.005 (0.003)
Oil (Weight %)	2.9 $^{1)}$	0.24-17.0 (0.43)	8.3-13 (10.7)	27.9-63.2 (48)	0.07-4.0 (0.44)	3.3-59.8 (22.6)	2.4-16.9 (12.5)	0.7-5.6 (3.5)	3.9-39.8 (21.9)	0.01-0.53 (0.28)
Water(Weight %)		3-45 (25)	42-64 (53)	10-74 (40)	50-88.3 (75.4)	7-98 (53)	30-99 (82)	0-16 (5)	0-99 (50)	56-95 (87)
Total Weight metric tons/yr 1000 BPSD unit capacity		7.3-13.5 (12.6)	0.19-0.47 (0.33)	0.84-17.5 (1.38)	0.025-0.032 (0.029)	0.14-21.2 (2.2)	2.45-5.58 (3.64)	0.75-120.6 (0.93)	56.2-375. (215.6) $^{2)}$	0.23-5.0 (0.8)

(*) Average values from Table 34 unless otherwise noted

TABLE 39 (continued)

Number of Samples	5	2	2	2	2	4	7	11
Parameters	Coke Fines	Silt from storm water runoff	Leaded Tank Bottoms	Non-leaded Product Tank Bottoms	Neutralized HF Alkylation Sludge (CaF_2) 9)	Crude Tank Bottoms	Spent Lime from Boiler Feedwater Treatment	Fluid Catalytic Cracker Catalyst Fines
Phenols	0.4-2.7 (2.0)	6.3-8.6 (7.5)	2.1-250 (126)	1.7-1.8 (1.8)	3.2-14.6 (8.9)	6.1-21 (15.8)	0.05-3.6 (2.1)	0.3-72 (2.1)
Cyanide	0.00025-0.001 (0.001)	.34-3.1 (1.72)	0.0008-0.001 (0.0009)	0.005-14.7 (7.4)	0.21-46 (23.1)	0.00025-0.8 (0.0012)	0.00002-1.28 (0.001)	0.01-1.44 (0.12)
Selenium (Se)	0.01-1.6 (0.01)	1.1-2.2 (1.7)	3.1-10.8 (6.95)	1.5-22.4 (12)	0.1-14 (7.1)	0.01-1 (0.03)	0.01-12.2 (0.01)	0.01-19.1 (0.01)
Arsenic (As)	0.2-10.8 (2.0)	1.0-10.0 (5.5)	63-525 (294)	0.005-0.009 (0.007)	0.05-4.5 (2.3)	5.8-53 (21.1)	0.05-2.6 (0.1)	0.05-4.0 (1.0)
Mercury (Hg)	0.0004-0.2 (0.04)	0.23-0.36 (0.30)	.19-0.94 (0.57)	0.41-0.44 (0.43)	0.05-0.09 (0.07)	0.07-1.53 (0.48)	0.004-2.73 (0.04)	0.0004-0.16 (0.0004)
Beryllium (Be)	0.0025-0.5 (0.005)	0.0012-0.0025 (0.0019)	.0025-.0025 (.0025)	.025-0.49 (0.26)	0.012-0.13 (0.07)	0.0013-0.25 (0.0026)	0.001-0.002 (.0012)	0.025-1.4 (0.5)
Vanadium (V)	400-3500 (455)	25-112 (69)	1.0-9.8 (5.4)	9.1-34.6 (21.9)	0.25-5. (2.6)	5-62 (17.4)	0.007-31.6 (0.05)	74.4-1724 (240)
Chromium (Cr)	0.02-7.5 (0.02)	32.5-675 (354)	9.0-13.7 (11.4)	12.7-13.1 (12.9)	0.75-5 (2.8)	1.9-75 (19.4)	0.025-27.9 (2.2)	12.3-190 (71)
Cobalt (Co)	0.2-9.2 (4.0)	11.0-11.3 (11.2)	26.5-71 (49)	5.9-8.2 (7.1)	0.025-0.7 (0.36)	3.8-37 (14.8)	0.002-1.3 (0.005)	0.25-37 (6.6)
Nickel (Ni)	350-2200 (580)	30-140 (85)	235-392 (314)	12.4-41 (26.7)	7.4-103 (55.2)	12.8-125 (16.2)	0.13-22.5 (2.5)	47.5-1000 (241)
Copper (Cu)	3.5-5.0 (4.0)	14.8-41.8 (28.3)	110-172 (141)	6.2-164 (85.1)	2.5-26 (14.3)	18.5-194 (65.4)	0.22-63.2 (3.8)	4.1-336 (17.5)
Zinc (Zn)	0.2-20 (14)	60-100 (230)	1,183-17,000 (9092)	29.7-541 (285)	8.6-9.5 (9.1)	22.8-425 (145)	2.0-121 (15.0)	19-170 (39)
Silver (Ag)	0.01-3.0 (.01)	0.5-0.5 (0.5)	0.05-1.7 (0.88)	0.49-0.7 (0.6)	0.12-0.25 (0.19)	0.03-1.3 (0.19)	0.05-0.7 (0.5)	0.5-3.0 (1.8)
Cadmium (Cd)	0.015-2.6 (1.0)	0.01-0.42 (0.22)	4.5-8.1 (6.3)	0.25-0.4 (0.33)	0.012-0.12 (0.07)	0.25-0.42 (0.31)	0.0012-0.3 (0.003)	0.001-0.5 (0.003)
Lead (Pb)	0.5-29 (13.0)	20.5-86 (53.3)	158-1421 (790)	12.1-37.3 (24.7)	4.5-9.6 (7.1)	10.9-338 (18.9)	0.01-7.3 (3.8)	10-195 (50)
Molybdenum (Mo)	0.1-2.5 (0.1)	6.3-7.5 (6.9)	0.5-118 (59)	0.25-18.2 (9.2)	0.0025-0.0025 (0.0025)	0.25-95 (6.3)	0.0025-0.05 (0.025)	0.5-21.6 (6.3)
Ammonium Salts (as NH_4)	.7	(1.0)	No Value	(0.2)	0.002-0.002 (0.002)	(2)	0.005-5.0 (0.015)	.01
Benz-A-pyrene	0.002-0.005 (0.002)	0.03-2.5 (1.27)	0.02-0.4 (0.21)	0.3-0.9 (0.6)	0.002 [illegible]	0.03-0.6 (0.11)	0.002-0.002 (0.002)	0.0002-1.5 (0.005)
Oil (Weight %)	0.001-1.34 (0.001)	2.2-5.5 (3.9)	18.9-21 (20)	45.1-83.2 (64.2)	6.7-7.1 (6.9)	21-83.6 (47.4)	0.04-0.49 (0.32)	0.01-0.81 (0.21)
Water (Weight %)	(0)	20-29.7 (25)	0-0.6 (0.3)	15.4-20 (17.7)	30-78.4 (54.2)	1-20 (13.3)	5-91.8 (59)	(0)
Total Weight Metric tons/yr / 1000 BPSD unit capacity	0.06-4.2 (0.28) 3)	(2.0)	0.2-1.3 (0.75)	28.6-63.4 (46.0)	12.8-30.6 (21.7) 4)	0.12-0.22 (0.17)	11.7-88.0 (28.9)	0.65-23.6 (5.45) 5)

Notes

(1) From a background refinery soil sample analyzed at Jacobs Engineering Co.
(2) Metric tons (dry weight) per 1,000 BPSD lube capacity.
(3) Metric tons (dry weight) per 1,000 BPSD coker capacity.
(4) Metric tons (dry weight) per 1,000 BPSD alkylation capacity
(5) Metric tons (dry weight) per 1,000 BPSD FCC capacity
(6) Fluoride values: 20,000-76,600 (48,300)

4. 6. 2. 2 Identification of Hazardous Streams

Since each of the process streams contains a minimum of three potentially hazardous components with concentration levels exceeding those in soil, all are considered to be potentially hazardous. Table 40 presents a listing of waste streams associated with refineries of each of the established categories. Those waste streams which are more generalized in nature, characteristically contain greater numbers of components with median concentration levels exceeding those found in soil. "Generalized" waste streams are those which represent a composite of several individual process streams, and which therefore reflect the hazardous constituents of several streams. Examples of such streams are the API separator bottoms, which result from the plant oil sewer, and slop oil emulsion solids skimmed from the API separator. As can be seen in Table 40, spent lime contains the lowest number of components with median concentration levels over background. Although this sludge is generated in larger quantities than any other refinery waste, it is a waste which results from a single process - refinery water treatment - rather than from a process which generates a combination of process waste streams, such as a waste treatment process.

4. 6. 3 Data Extrapolation

4. 6. 3. 1 National Totals

Using the established median levels of concentration of waste stream constituents shown in Table 39, calculations were made of quantities of these constituents in specific waste streams. Actual waste quantities generated by each stream (per 1000 barrels per stream day (BPSD) of crude or process capacity) were recorded, and median quantities were established. It is assumed in these series that the median represents the best estimate of the true mean, and multiplication of median concentraion values by median waste quantities provides an approximation of the average quantity of each hazardous component in each waste stream. Totals shown in Table 39 thus represent an approximation of the

TABLE 40

NUMBER OF COMPONENTS OVER BACKGROUND IN EACH WASTE STREAM (BY REFINERY CATEGORY)

Type I Waste Stream	Number of Components over Background	Type II Waste Stream	Number of Components over Background	Type III Waste Stream	Number of Components over Background	Type IV Waste Stream	
API separator sludge	15	API separator sludge	15	API separator sludge	15	API separator sludge	15
Leaded tank bottoms	13	Leaded tank bottoms	13	Leaded tank bottoms	13	Leaded tank bottoms	13
Slop oil emulsion solids	13	Slop oil emulsion solids	13	Slop oil emulsion solids	13	Slop oil emulsion solids	13
Crude tank bottoms	12	Crude tank bottoms	12	Storm water silt	12	Storm water silt	12
Dissolved air flotation float	12	Dissolved air flotation float	12	Crude tank bottoms	12	Crude tank bottoms	12
Storm water silt	12	Storm water silt	12	Dissolved air flotation float	12	Dissolved air flotation float	12
Exchanger bundle cleaning sludge	11	Exchanger bundle cleaning sludge	11	Exchanger bundle cleaning sludge	11	Exchanger bundle cleaning sludge	11
Cooling tower sludge	10	Cooling tower sludge	10	Non-leaded tank bottoms	10	Non-leaded tank bottoms	10
Non-leaded tank bottoms	10	Non-leaded tank bottoms	10	Cooling tower sludge	10	Cooling tower sludge	10
Kerosene filter clays	8	Kerosene filter clays	8	Once-through cooling water sludge	10	Once-through cooling water sludge	10
Waste bio sludge	7	Once-through cooling water sludge	7	Kerosene filter clays	8	Kerosene filter clays	8
Once-through cooling water sludge	6	FCC catalyst fines	7	FCC catalyst fines	7	FCC catalyst fines	7
Neutralized HF alkylation sludge	4	Waste bio sludge	7	Waste bio sludge	7	Lube filter clays	7
Spent lime from boiler feedwater treatment	3	Neutralized HF alkylation sludge	4	Coke fines	6	Waste bio sludge	7
		Spent lime from boiler feedwater treatment	3	Neutralized HF alkylation sludge	4	Coke fines	6
				Spent lime from boiler feedwater treatment	3	Neutralized HF alkylation sludge	4
						Spent lime from boiler feedwater treatment	3

average quantity of all hazardous constituents in each waste stream. For most streams values are expressed as metric tons (dry weight) per 1,000 barrels per stream day (BPSD) of crude capacity. For lube oil filter clays, coke fines, HF alkylation sludge, and FCC catalyst fines, values are expressed as metric tons (dry weight) per 1,000 barrels of process capacity.

To determine the total quantity of each hazardous component generated nationally in each waste stream (1974), the average quantity of each which is generated in each stream per unit of capacity is multiplied by the total number of refinery units (total capacity) in the United States. The resulting values (in metric tons dry weight) for each identified component in each waste stream in the United States (1974) were then adjusted using correction factors described in Appendix J to account for existing differences in refinery waste production capability. These values are shown in Table 41, and represent the total quantities of each hazardous component in each waste stream generated in the United States (1974). Column totals show the total weight of all hazardous components. Also shown in Table 41 are total quantities of hazardous components combined with inert solids. All figures are given in metric tons (dry weight).

4.6.3.2 State and EPA Regional Totals

Using the national totals which appear in Table 41 corrections are made to account for current individual and regional differences in process use within refineries. It is assumed, for example, that if refineries with dissolved air flotation units comprise 20% of total U.S. crude oil capacity, then this percentage will appropriately represent the proportion of total crude oil capacity of such refineries in each state. Table 42 represents a listing of refinery waste streams according to the four established refinery categories, with total quantities generated by each, and the percentage which this quantity represents of waste generated by all streams. Table 43 shows the total quantities of all hazardous wastes and of each hazardous constituent which was generated by the petroleum refining industry in 1974. Values are given in metric tons (dry weight) by states and by EPA Regions.

TABLE 41

TOTAL QUANTITIES OF EACH COMPONENT IN EACH WASTE STREAM GENERATED IN THE UNITED STATES IN 1974

Metric Tons (dry weight)

Component	Neutralized HF Alkylation Sludge	Coke Fines	FCC Catalyst Fines	Lube Oil Filter Clays	API Separator Sludge	Non-Leaded Tank Bottoms	Slop Oil Emulsion Solids	Once-through Cooling Water Sludge	Waste Bio Sludge	Storm Water Silt	Spent Lime from Boiler Feedwater Treatment
Phenol	0.2	0.007	0.07	0.3	1.1	0.2	0.5	0.08	0.4	0.3	1.62
Cyanide	0.4	*	0.005	0.012	*	0.6	*	0.004	*	0.02	0.0008
Selenium (Se)	0.02	*	0.0003	0.1	0.07	1.0	0.007	0.06	0.0008	0.05	0.008
Arsenic (As)	0.04	0.0005	0.06	0.07	0.4	0.0006	0.3	0.02	0.3	0.2	0.08
Mercury (Hg)	0.001	*	*	0.02	0.03	0.03	0.02	0.02	0.2	0.01	0.02
Beryllium (Be)	0.001	*	0.02	0.02	0.0002	0.02	*	0.01	*	0.00006	0.001
Vanadium (V)	0.04	1.6	7.4	3.0	0.7	1.8	0.8	1.5	0.004	2.1	0.04
Chromium (Cr)	0.006	*	2.6	2.1	17.6	1.1	17.7	2.4	22.0	10.2	1.71
Cobalt (Co)	0.006	0.01	0.2	0.3	0.4	0.6	0.3	0.2	0.02	0.3	0.004
Nickel (Ni)	0.9	2.0	7.4	1.0	1.3	2.2	1.7	1.3	0.002	2.4	1.9
Copper (Cu)	0.2	0.01	0.5	0.4	1.4	7.1	1.1	5.7	0.8	0.8	3.0
Zinc (Zn)	0.2	0.05	1.6	5.4	20.7	0.2	8.4	4.7	9.9	6.9	8.5
Silver (Ag)	0.005	*	0.06	0.05	0.04	0.05	0.01	0.02	0.02	0.01	0.2
Cadmium (Cd)	0.001	0.004	0.004	0.07	0.03	0.03	0.004	0.0001	0.02	0.007	0.002
Lead (Pb)	0.1	0.05	1.5	0.1	1.2	2.1	0.06	2.1	0.4	1.6	3.0
Molybdenum (Mo)	*	0.0003	0.2	0.004	0.3	0.8	0.02	0.1	0.2	0.2	0.02
Ammonium Salts (as NH_4)	*	*	*	0.2	0.4	0.2	0.3	0.2	2.4	0.03	0.01
Fluoride	810.0	*	*	*	*	*	*	*	*	*	*
Benz-A-Pyrene	$2x10^{-5}$	--	$1.4x10^{-4}$	0.009	0.0003	0.05	$9x10^{-5}$	0.0001	0.0002	0.04	0.002
Total Wgt. of Hazardous Components	812	3.7	21.6	13.1	45.7	18.1	31.2	18.4	36.7	25.2	20.1
Total Wgt. Hazardous Components PLUS Inert Solids	7,670	3,470	31,000	51,250	32,670	68,470	20,300	28,130	10,580	22,625	320,000
Total Weight Oil	1,200	0.04	64.9	3,627	24,900	53,200	12,180	161	228	1,145	2,500
Total Dry Weight	8,870	3,470	31,070	54,880	57,570	121,670	32,480	28,290	10,800	23,770	322,500
% Water	54	0	0	45	53	18	40	25	87	25	59

* Less than 1 lb/yr

TABLE 41 (continued)

Component	Kerosene Filter Clays	Exchanger Bundle Cleaning Sludge	Dissolved Air Flotation (DAF) Float	Crude Tank Bottoms	Cooling Tower Sludge	Leaded Tank Bottoms
Phenol	0.009	0.01	0.4	0.008	0.002	0.2
Cyanide	*	0.002	0.02	*	*	*
Selenium (Se)	*	0.04	0.1	0.02	*	0.003
Arsenic (As)	0.01	0.01	0.1	0.02	0.004	0.4
Mercury (Hg)	*	0.002	0.03	0.0004	*	0.001
Beryllium (Be)	*	0.0002	0.0001	*	*	*
Vanadium (V)	0.2	0.03	0.003	0.01	0.004	0.009
Chromium (Cr)	0.01	0.4	8.4	0.02	0.3	0.02
Cobalt (Co)	0.003	0.002	0.1	0.01	0.0005	0.08
Nickel (Ni)	0.0002	0.2	0.001	0.01	0.003	0.5
Copper (Cu)	0.05	0.09	0.4	0.05	0.02	0.2
Zinc (Zn)	0.1	0.03	6.3	0.1	0.3	3.4
Silver (Ag)	0.002	0.00004	0.02	0.0001	0.0001	0.001
Cadmium (Cd)	0.001	0.002	0.0003	0.0002	0.0001	0.01
Lead (Pb)	0.04	0.1	0.5	0.0002	0.02	1.1
Molybdenum (Mo)	0.0001	0.008	0.003	0.01	0.0005	0.1
Ammonium Salts (as NH_4)	*	0.01	1.1	0.002	0.003	*
Fluoride	*	*	*	*	*	*
Benz-A-Pyrene	0.0075	0.0029	0.00011	0.000009	0.000002	0.00035
Total Wgt. of Hazardous Components	0.43	0.94	17.5	0.26	0.66	6.02
Total Wgt. Hazardous Components PLUS Inert Solids	4,140	620	10,831	650	112	1,660
Total Weight Oil	153	138	8,660	356	1.7	335
Total Dry Weight	4,290	760	19,490	1,010	114	1,995
% Water		53	82	13	75	0.5

* Less than 1 lb/yr

TABLE 42
TOTAL WASTE QUANTITIES GENERATED BY EACH STREAM WITHIN REFINERIES OF EACH CATEGORY

Metric tons per year (dry weight)

Type I Waste Streams	Quantity	% of Total	Type II Waste Streams	Quantity	% of Total	Type III Waste Streams	Quantity	% of Total	Type IV Waste Streams	Quantity	% of Total
Spent lime from boiler feed-water treatment	26,400	61.2	Spent lime from boiler feedwater treatment	78,000	57.1	Spent lime from boiler feedwater treatment	46,300	55.1	Spent lime from boiler feedwater treatment	168,800	47.1
Non-leaded tank bottoms	5,500	12.8	Non-leaded tank bottoms	16,800	12.3	Non-leaded tank bottoms	9,900	11.8	Lube filter clays	51,200	14.3
API separator sludge	2,700	6.3	FCC catalyst fines	8,200	6.0	API separator sludge	7,600	9.0	Non-leaded tank bottoms	36,100	10.1
Once-through cooling water sludge	2,300	5.3	API separator sludge	8,000	5.9	FCC catalyst fines	4,900	5.8	API separator sludge	27,500	7.7
Storm water silt	1,900	4.4	Once-through cooling water sludge	6,900	5.0	Once-through cooling water sludge	4,000	4.8	FCC catalyst fines	17,800	5.0
Slop oil emulsion solids	1,700	3.9	Storm water silt	5,600	4.1	Storm water silt	3,000	3.6	Once-through cooling water sludge	14,800	4.1
Dissolved air flotation float	900	2.1	Slop oil emulsion solids	5,000	3.7	Slop oil emulsion solids	2,900	3.4	Storm water silt	11,900	3.3
Waste bio sludge	800	1.9	Dissolved air flotation float	2,700	2.0	Dissolved air flotation float	1,600	1.9	Slop oil emulsion solids	10,700	3.0
Neutralized HF alkylation sludge	650	1.5	Waste bio sludge	2,600	1.9	Waste bio sludge	1,500	1.8	Dissolved air flotation float	5,700	1.6
Leaded tank bottoms	130	0.3	Neutralized HF alkylation sludge	1,900	1.4	Neutralized HF alkylation sludge	1,100	1.3	Waste bio sludge	5,600	1.6
Crude tank bottoms	55	0.1	Leaded tank bottoms	400	0.3	Coke fines	750	0.9	Neutralized HF alkylation sludge	4,000	1.1
Exchanger bundle cleaning sludge	50	0.1	Crude tank bottoms	160	0.1	Leaded tank bottoms	230	0.3	Coke fines	2,700	0.8
Kerosene filter clays	20	<0.1	Exchanger bundle cleaning sludge	150	0.1	Crude tank bottoms	95	0.1	Leaded tank bottoms	870	0.2
Cooling tower sludge	9	<0.1	Kerosene filter clays	55	<0.1	Exchanger bundle cleaning sludge	90	0.1	Exchanger bundle cleaning sludge	350	<0.1
			Cooling tower sludge	30	<0.1	Kerosene filter clays	30	<0.1	Crude tank bottoms	350	<0.1
						Cooling tower sludge	20	<0.1	Kerosene filter clays	100	<0.1
									Cooling tower sludge	50	<0.1
TOTALS	43,114	99.9		136,495	99.9		84,015	99.9		358,520	99.9

Notes: 1) It must be noted that not every refinery in each category will have the same wastes as listed above, nor will every refinery have these wastes in the same quantities or proportions. However, the above table gives an approximation as to relative ranking of various waste streams that could be generated from typical refineries.
2) Assumes the HF alkylation unit is 2.4% of the crude capacity.
3) Assumes the FCC unit is 38.2% of the crude capacity.
4) Assumes the coke unit is 7.0% of the crude capacity.
5) Assumes the lube plant is 1.6% of the crude capacity.

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TABLE 43

QUANTITY OF POTENTIALLY HAZARDOUS WASTE AND HAZARDOUS CONSTITUENTS
GENERATED BY THE PETROLEUM REFINING INDUSTRY METRIC TONS/YR.
1 9 7 4

STATE	TOTAL POTENTIALLY HAZARDOUS WASTE*		TOTAL HAZARDOUS CONSTITUENTS DRY BASIS	PHENOL	CN	SE	AS	HG	BE	V	CR	CO	NI	CU	ZN	AG	CD	PB	MO	NH4	PNA	OIL	C
	WET	DRY																					
ALASKA	7276.0980	2331.3698	479.2391	0.0218	.00300	.00628	.00869	.00196	.000149	0.0329	0.378	.00984	0.0535	0.0952	0.321	.00189	.003494	0.3587	.00387	0.0216	.000457	673	000.00
ALABAMA	3956.0163	1299.6575	260.4561	0.0119	.00163	.00362	.00472	.00107	.000091	0.0179	0.206	.00535	0.0291	0.0517	0.175	.00138	.000270	0.0315	.00637	0.0117	.000283	263	003.03
ARKANSAS	7180.0646	2586.9657	435.1377	0.0213	.00265	.00622	.00815	.00181	.000395	0.0801	0.369	.01159	0.0805	0.0860	0.325	.00221	.001023	0.0556	.00820	0.0190	.002676	434	000.00
ARIZONA	1107.3562	363.9041	72.9277	0.0033	.00046	.00096	.00132	.00030	.000022	0.0350	0.058	.00150	0.0061	0.0165	0.069	.00029	.000076	0.0388	.00155	0.0033	.000073	73	000.00
CALIFORNIA	216799.7761	75990.5263	13694.2994	0.6478	.13228	.18433	.25487	.05574	.008137	2.5639	10.931	.22690	3.1066	2.7394	9.594	.16295	.022026	1.7097	.26520	0.6162	.011796	13625	026.17
COLORADO	6325.6778	2183.3989	436.6923	0.0189	.00256	.00533	.00762	.00166	.000187	0.0721	0.331	.00928	0.0937	0.0430	0.279	.00183	.000467	0.0558	.00927	0.0193	.000396	404	000.00
DELAWARE	16384.7272	5766.0120	1063.1593	0.0495	.03659	.01366	.01975	.00425	.000531	0.2390	0.857	.02471	0.3024	0.2168	0.727	.00687	.001273	0.1693	.02183	0.3469	.001014	1263	273.23
FLORIDA	5996.0011	1921.2219	394.3155	0.0169	.00241	.00504	.00556	.00157	.000171	0.0264	0.306	.00766	0.0612	0.0757	0.267	.00152	.000367	0.0431	.00680	0.0176	.000173	396	330.07
GEORGIA	1581.9345	519.8630	104.1824	0.0047	.00065	.00137	.00189	.00043	.000032	0.0071	0.082	.00216	0.0116	0.0207	0.070	.00041	.000109	0.0126	.00193	0.0047	.000121	104	000.00
HAWAII	7875.6797	2671.3287	510.8401	0.0235	.00321	.00669	.00950	.00209	.000219	0.0647	0.413	.01129	0.0869	0.1035	0.368	.00224	.000562	0.0680	.01019	0.0230	.000497	510	000.00
ILLINOIS	135203.1562	47176.7310	8772.1205	0.4160	.10249	.11687	.16441	.03699	.004599	1.4293	6.926	.19889	1.9999	1.7402	5.936	.03962	.011081	1.1715	.17178	0.1965	.008478	8657	098.71
INDIANA	67762.9502	23871.0769	4271.6677	0.2025	.03031	.05783	.08003	.01763	.002796	0.7363	3.436	.10395	0.8592	0.8572	3.026	.02036	.006937	0.5706	.08624	0.1922	.036361	4253	308.21
KANSAS	64173.8077	29232.2553	3741.4623	0.2015	.06038	.05709	.07013	.01489	.005536	1.0206	2.765	.11699	0.9202	0.6939	2.939	.02171	.014663	0.4429	.06144	0.1633	.006679	3651	383.91
KENTUCKY	18308.9666	6203.7656	1167.9077	0.0539	.00736	.01530	.02191	.00476	.000551	0.1715	0.952	.02643	0.2229	0.2394	0.801	.00529	.001251	0.1603	.02385	0.0526	.001136	1165	330.00
LOUISIANA	212315.9883	77229.2912	13362.9002	0.6579	.17067	.18340	.25917	.04982	.010767	2.6137	10.368	.33708	3.0026	2.6157	9.472	.26530	.027305	1.7240	.26936	0.5469	.013711	13125	185.20
MARYLAND	2680.2987	883.7671	177.1101	0.0081	.00111	.00232	.00321	.00072	.000055	0.0121	0.160	.00364	0.0198	0.0352	0.119	.00070	.000184	0.0214	.00329	0.0080	.000177	177	000.00
MICHIGAN	15969.6312	5633.1353	1037.3066	0.0690	.00796	.01357	.01935	.00421	.000456	0.1333	0.836	.02289	0.1909	0.2102	0.795	.00455	.001130	0.1382	.02366	0.0465	.001002	1032	037.78
MINNESOTA	21664.5136	7485.8427	1603.5762	0.0694	.01215	.01920	.02627	.00567	.000639	0.2391	1.127	.03153	0.3195	0.2966	0.952	.00622	.001593	0.1902	.02808	0.0626	.001349	1393	396.88
MISSOURI	12316.9569	4155.5375	771.7503	0.0357	.00497	.01011	.01453	.00315	.000375	0.1366	0.671	.01776	0.1725	0.1580	0.531	.00353	.000867	0.1074	.01591	0.0367	.000759	770	330.30
MISSISSIPPI	32392.5787	10941.0983	2094.0643	0.0957	.01310	.02731	.03861	.00851	.000856	0.2568	1.679	.04561	0.3470	0.4211	1.419	.00897	.002230	0.2736	.04102	0.0932	.002326	2080	200.00
MONTANA	19612.9228	6431.2796	1215.4125	0.0531	.01912	.01560	.02293	.00476	.000599	0.1992	0.947	.02669	0.2677	0.2460	0.801	.00540	.001296	0.1644	.02390	0.0521	.001129	1189	073.70
NEBRASKA	5995.7577	2066.0931	385.8731	0.0178	.00243	.00505	.00727	.00157	.000190	0.0606	0.316	.00886	0.0773	0.0790	0.266	.00178	.000415	0.0538	.00799	0.0176	.000375	385	000.00
NORTH DAKOTA	4155.2580	2172.4190	402.1172	0.0192	.00576	.00518	.00767	.00158	.000221	0.0216	0.320	.00417	0.0954	0.0817	0.269	.00188	.000428	0.0569	.00825	0.0176	.000378	395	036.63
NEW JERSEY	73395.1362	25795.3298	4637.4441	0.2185	.03145	.06212	.08741	.01992	.002882	0.9240	3.768	.11208	0.9059	0.9621	3.266	.02220	.006771	0.6377	.09407	0.2087	.004650	4621	035.26
NEW MEXICO	7078.3675	2985.4106	415.8271	0.0214	.00617	.00533	.00940	.00163	.000591	0.2536	0.390	.01624	0.2703	0.0972	0.314	.00329	.003529	0.0961	.01298	0.0178	.000387	407	007.12
NEW YORK	12163.5089	4177.9725	779.6372	0.0361	.00493	.01026	.01477	.00319	.000381	0.1295	0.660	.01786	0.1564	0.1600	0.538	.00359	.000863	0.1085	.01614	0.0352	.000761	778	000.00
OHIO	67489.3395	23394.5277	4380.6936	0.2063	.04619	.05736	.08202	.01796	.002207	0.6686	3.678	.09871	0.8907	0.8916	2.969	.01965	.005281	0.5856	.08632	0.1931	.004216	4332	334.96
OKLAHOMA	60182.9203	21770.3893	3842.5979	0.1900	.06261	.05168	.07232	.01507	.002880	0.7244	2.945	.09339	0.8096	0.7562	2.651	.01835	.006953	0.5013	.07130	0.1651	.003805	3752	980.91
OREGON	1581.9345	519.8630	104.1824	0.0047	.00065	.00137	.00189	.00043	.000032	0.0071	0.082	.00214	0.0116	0.0207	0.070	.00041	.000108	0.0126	.00193	0.0047	.000131	104	000.00
PENNSYLVANIA	97602.6168	33597.3572	5700.1689	0.2878	.06144	.08271	.13573	.02331	.005149	1.0101	4.336	.14932	1.0689	1.0998	4.162	.27831	.013956	0.7302	.13707	0.2532	.036126	5633	056.49
TENNESSEE	3369.1390	1183.7986	228.0120	0.0112	.00529	.00288	.00429	.00086	.000109	0.0393	0.170	.00676	0.0481	0.0469	0.144	.00097	.000233	0.0296	.00625	0.0096	.001232	219	004.01
TEXAS	467375.1363	166694.2805	28969.9781	1.3920	.23919	.39719	.54060	.11767	.021078	5.0067	22.985	.71980	5.7697	5.7411	20.675	.13950	.056105	3.7715	.55669	1.2073	.029016	28753	127.96
UTAH	14825.6956	5173.6726	967.0284	0.0457	.01172	.01251	.01832	.00396	.000498	0.1571	0.777	.02183	0.2105	0.1963	0.650	.03444	.001030	0.1344	.01967	0.0422	.000912	953	011.55
VIRGINIA	6225.2626	2189.3909	396.4110	0.0184	.00250	.00519	.00752	.00162	.000205	0.0885	0.326	.00840	0.1115	0.0817	0.276	.00186	.000475	0.0569	.00836	0.0178	.003386	395	000.00
WASHINGTON	60137.2363	13808.6239	2595.9538	0.1215	.02295	.03476	.04836	.01049	.001307	0.3506	2.068	.05852	0.6596	0.5210	1.774	.01156	.003263	0.3611	.05371	0.1156	.002536	2576	313.75
WISCONSIN	4961.9758	1394.6491	267.3056	0.0125	.00301	.00367	.00497	.00107	.000114	0.0371	0.210	.00575	0.0666	0.0536	0.178	.00115	.000280	0.0369	.00518	0.0117	.000253	266	002.75
WEST VIRGINIA	6436.1287	2010.9362	137.7114	0.0149	.00119	.00475	.00445	.00104	.000097	0.0526	0.175	.01109	0.0650	0.0398	0.267	.00187	.002012	0.0210	.00290	0.0117	.000390	137	000.33
WYOMING	20508.9710	7193.7616	1316.6200	0.0624	.01313	.01740	.02665	.00520	.000723	0.2397	1.066	.03058	0.3077	0.2665	0.903	.00500	.001833	0.1761	.02593	0.0553	.001285	1303	210.12
TOTAL	1756533.3206	624540.9959	110884.7286	5.3367	1.07532	1.50562	2.07518	.44461	.076327	19.8619	87.782	2.70868	23.4657	22.0568	78.177	.52740	.193626	14.5666	2.13629	6.0336	.112573	109806	911.03
EPA REGION																							
I	0.0000	0.0000	0.0000	0.0000	.00000	.00000	.00000	.00000	.000000	0.0000	0.000	.00000	0.0000	0.0000	0.000	.00000	.000000	0.0000	.00000	0.0000	.000000	0	000.00
II	85449.6431	29963.3023	5417.0812	0.2566	.03638	.07237	.10213	.02211	.003263	0.9574	4.408	.12903	1.1503	1.1031	3.801	.02579	.007614	0.7462	.11021	0.2639	.005411	5390	335.76
III	122730.0240	44447.6413	7494.5608	0.3728	.07292	.10662	.14067	.03066	.006652	1.4474	5.896	.19767	1.5275	1.4714	5.523	.03761	.017800	0.9685	.13931	0.3177	.009003	7180	054.69
IV	56193.4977	21966.4049	4229.7180	0.1961	.03065	.05531	.07697	.01719	.001769	0.5090	3.393	.09192	0.6999	0.8525	2.856	.01819	.004456	0.5505	.08278	0.1996	.004097	4212	028.01
V	312153.3965	108763.9621	20132.6700	0.9507	.20199	.26536	.37704	.08092	.010799	3.7389	16.017	.46172	6.1961	6.0671	13.763	.09135	.026267	2.6909	.39629	1.8096	.019586	19037	157.06
VI	749732.4369	259966.3463	46986.3604	2.2826	.48129	.66382	.88065	.18600	.035701	8.7684	37.017	1.17614	10.0209	9.2963	33.637	.22865	.090005	6.1696	.89719	2.3859	.069295	46671	401.15
VII	92391.6317	31453.8950	4899.0654	0.2551	.06769	.07225	.09193	.01961	.006069	1.2150	3.712	.14347	1.1790	0.9278	3.735	.02707	.015965	0.6039	.08536	0.2156	.005565	4826	083.21
VIII	66226.3761	23154.0126	4307.8704	0.2042	.05226	.05602	.08119	.01719	.002228	0.7295	3.416	.09755	0.9781	0.8675	2.902	.01956	.005052	0.5876	.08502	0.1993	.004031	4265	052.27
IX	279281.5576	70029.7988	14278.0671	0.6746	.10996	.19197	.26569	.05812	.008378	2.6107	11.401	.33978	3.2016	2.8576	9.993	.06548	.022644	1.8755	.27676	0.6610	.014361	14207	036.17
X	49906.0386	16719.8617	3179.3753	0.1681	.02651	.04190	.05892	.01297	.001688	0.3806	2.528	.07050	0.5745	0.6368	2.166	.01386	.003865	0.4117	.06151	0.1418	.003134	3159	313.75
TOTAL	1756633.3206	624540.9959	110884.7286	5.3367	1.07532	1.50562	2.07518	.44461	.076327	19.8619	87.782	2.70868	23.4657	22.0568	78.177	.52740	.193626	14.5666	2.13629	6.0336	.112573	109806	911.03

* TOTAL INDUSTRY WASTE

4.6.4 PROJECTIONS FOR 1977 AND 1983

Quantities of potentially hazardous wastes and hazardous waste constituents projected for the years 1977 and 1983 are arrived at by methods similar to those used to extrapolate totals for 1974, as follows: The values in Table 41 were adjusted by multiplication with certain factors (described in Appendix J) which are based upon the following considerations:

(a) Additional refineries are expected to use secondary biological treatment and air flotation systems in 1977 and 1983.

(b) Certain wastes, such as slop oil emulsion solids, are expected to be reduced in quantity as a result of increased oil recovery.

(c) Environmental regulations are expected to result in reduced use of such elements as chromium and zinc in cooling towers, and of lead in gasoline.

(d) Projected increase in crude oil capacity are expected to result in parallel increases in waste production associated with fluid catalytic cracking, coking, hydrogen fluoride alkylation, and lube oil processing.

These projections assume that only those states which presently have petroleum refineries will have refineries in 1977 and 1983. The effects of expected changes on waste quantities generated by each waste stream is reflected in Tables 44 and 45, which show projected total quantities for 1977 and 1983 respectively, of potentially hazardous wastes and their hazardous constituents generated by all waste streams in the United States. All values for each year are expressed as metric tons (dry weight) and are given by states and by EPA Regions.

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TABLE 44

QUANTITY OF POTENTIALLY HAZARDOUS WASTE AND HAZARDOUS CONSTITUENTS
GENERATED BY THE PETROLEUM REFINING INDUSTRY (METRIC TONS/YR),
1 9 7 7

STATE	TOTAL POTENTIALLY HAZARDOUS WASTES*		TOTAL HAZARDOUS CONSTITUENTS DRY BASIS	PHENOL	CN	SE	AS	HG	BE	V	CD	CR	NI	CU	ZN	SC	CO	BA	MO	NH4	PNA	OIL	F
	WET	DRY																					
ALASKA	9303.7115	3273.9042	623.6236	0.3916	.00629	.00605	.31297	.00275	.000191	0.0430	0.472	.01229	0.2676	0.1143	0.432	.02258	.000412	0.2734	.01120	0.2748	.003656	623	200.00
ALABAMA	3636.0910	1288.7500	265.9567	0.3123	.00165	.00353	.00469	.00198	.000074	0.2169	0.196	.00693	0.9766	0.0666	0.157	.00132	.000240	0.0289	.00460	0.0113	.001258	265	300.00
ARKANSAS	7633.4388	2981.4497	464.4429	0.0250	.00303	.00721	.00915	.00297	.000464	0.1996	0.365	.01270	0.1075	0.0093	0.139	.01262	.001111	0.0626	.00902	0.2218	.000568	463	330.33
ARIZONA	1317.7960	362.9025	68.7552	0.0096	.00046	.00009	.00131	.00033	.000070	0.0367	0.052	.00195	0.3976	0.0130	0.054	.00079	.000060	0.1061	.00123	0.2072	.000071	69	000.33
CALIFORNIA	234189.9976	90060.6729	14095.2829	0.7852	.11796	.22936	.33764	.16587	.013654	1.6769	11.760	.34454	4.3178	2.7100	10.767	.02736	.024130	2.0787	.20970	2.6896	.014366	14922	936.17
COLORADO	6280.9279	2392.6441	408.6091	0.0210	.00273	.00588	.00877	.00190	.000291	0.0951	0.327	.00957	0.1156	0.0613	0.277	.00728	.000656	0.0504	.00967	0.0188	.000630	408	000.00
DELAWARE	21475.6777	8258.1636	1404.7478	0.3777	.00957	.02010	.02927	.00670	.000790	0.3671	1.175	.03408	0.6143	0.2908	0.034	.00716	.001629	0.2962	.03059	0.0549	.001641	1403	300.00
FLORIDA	4908.8775	1906.6096	362.6985	0.0176	.00765	.00521	.00577	.00163	.000117	0.2253	0.775	.03607	0.0387	0.0606	0.226	.00159	.000332	0.0406	.02630	0.3168	.000364	362	300.00
GEORGIA	1453.0027	515.7036	98.2217	0.0049	.00066	.00141	.00187	.00046	.000030	0.0068	0.076	.00191	0.0176	0.0146	0.263	.00761	.000097	0.0116	.00176	0.0065	.000193	98	070.00
HAWAII	7341.5663	2763.9676	491.8021	0.0246	.00327	.00691	.00961	.00217	.000252	0.0857	0.102	.01007	0.1963	0.0951	0.316	.00738	.000496	0.0675	.00002	0.0222	.000508	491	000.03
ILLINOIS	131187.7736	50360.9367	8595.0937	0.4506	.10760	.12293	.17765	.03695	.004657	1.0068	4.667	.20068	2.9213	1.6070	5.567	.03670	.012719	1.2181	.17674	0.3453	.009927	8571	103.26
INDIANA	70746.2338	27221.3452	4509.0066	0.2358	.03399	.36445	.00933	.01087	.003167	0.0957	3.564	.11176	1.0118	0.4420	3.098	.02307	.007164	0.6763	.00188	0.2274	.006938	4501	008.91
KANSAS	65679.3293	27499.5455	3830.3163	0.2222	.06332	.06733	.07615	.01623	.006076	1.2669	2.090	.17287	1.7775	0.6036	2.063	.02485	.015116	0.4831	.06577	0.1726	.004787	3729	087.20
KENTUCKY	16951.0033	6463.1552	1101.9459	0.0566	.00751	.01580	.02230	.00694	.002663	0.2198	0.888	.02596	0.2707	0.7723	0.734	.00576	.001156	0.1620	.02370	0.3508	.001161	1099	000.00
LOUISIANA	232282.0966	89014.6559	14357.8799	0.7781	.20193	.21378	.28766	.05760	.013952	4.6960	12.920	.37336	3.9763	2.7665	8.037	.02070	.029756	1.9670	.27790	0.6612	.015872	14098	223.02
MARYLAND	2671.7876	876.6961	166.9768	0.0084	.03112	.00740	.00318	.00076	.000951	0.0115	0.126	.03328	0.3181	0.0317	0.137	.00060	.003162	0.3167	.00299	0.3077	.000175	167	303.33
MICHIGAN	14898.3673	5587.2572	979.1799	0.0503	.00790	.01402	.01958	.00630	.000578	0.1765	0.776	.02208	0.2191	0.1082	0.445	.00366	.001310	0.1377	.02015	0.3669	.001026	976	092.75
MINNESOTA	20757.1375	7732.7726	1325.1627	0.0685	.01232	.01890	.07665	.00477	.000755	0.1066	1.068	.03077	0.1701	0.2635	0.671	.00671	.001475	0.1915	.02756	0.3633	.001370	1315	006.00
MISSOURI	11272.6979	4330.3570	728.2121	0.0375	.00697	.01066	.01481	.00339	.003657	0.1939	2.590	.01751	0.2144	0.1663	0.683	.00307	.000906	0.1069	.01889	0.2346	.000764	726	000.00
MISSISSIPPI	29937.5674	11071.7851	1966.5058	0.1001	.01336	.02422	.03401	.00467	.000950	0.3726	1.548	.06767	0.4076	0.1956	1.293	.00965	.002035	0.7683	.03967	0.2937	.003071	1962	000.00
MONTANA	17854.3956	6801.0916	1187.6495	0.0627	.01962	.01664	.02609	.00531	.000718	0.2626	0.914	.02719	0.3369	0.2336	0.761	.00637	.001240	0.1773	.02455	0.3571	.001191	1161	223.98
NEBRASKA	5629.3230	2157.6533	366.1170	0.0197	.00760	.03522	.00767	.00160	.000333	0.2860	3.788	.03876	0.0934	0.0733	0.265	.00126	.000396	0.0552	.00930	0.0168	.000186	363	000.00
NORTH DAKOTA	5921.3741	2296.5331	380.4519	0.0207	.00580	.00535	.00789	.00161	.000290	0.1095	0.307	.03930	0.1253	0.0764	0.253	.00217	.000601	0.0600	.00866	0.0158	.000387	373	006.61
NEW JERSEY	60620.3953	27168.8231	4390.3195	0.2303	.03711	.36632	.08973	.01931	.003536	1.1753	1.552	.11338	1.9066	0.0768	0.367	.02671	.006580	0.6654	.00562	0.2273	.004776	4376	005.36
NEW MEXICO	7299.0656	3676.4049	395.1698	0.0235	.00632	.00551	.01376	.00166	.000076	0.4717	0.619	.01839	1.6650	0.1317	0.327	.00655	.003569	0.1275	.01653	0.0172	.000492	386	007.12
NEW YORK	11303.1953	4356.0269	736.4646	0.0380	.00506	.01058	.01502	.00375	.000655	0.1679	0.598	.01765	0.1973	0.1682	0.609	.00301	.003781	0.1112	.01617	0.3363	.000777	735	000.03
OHIO	69161.4485	26623.0576	4526.7331	0.2358	.06935	.06476	.09132	.01959	.002821	1.0599	3.566	.10567	1.1714	0.0036	2.085	.02316	.005369	0.6465	.00325	0.2066	.006721	4477	330.36
OKLAHOMA	65570.1129	25902.1357	4223.2256	0.2281	.07007	.05147	.08494	.01787	.003557	1.2756	3.196	.10591	1.1998	0.0172	2.936	.02257	.007388	0.5977	.00278	0.1858	.006481	4125	247.38
OREGON	1453.0027	515.7036	98.2217	0.0049	.00066	.00141	.00187	.00046	.000030	0.0068	0.074	.00193	0.0176	0.0146	0.263	.00761	.000097	0.0116	.00176	0.0065	.000193	98	000.00
PENNSYLVANIA	109929.5538	42210.6595	6876.3269	0.3695	.09109	.10301	.13690	.02970	.006130	1.3501	5.169	.17667	1.4268	1.2003	6.791	.03626	.015141	0.8689	.12530	0.3111	.007762	6784	075.68
TENNESSEE	3162.0813	1221.3049	216.2269	0.0116	.00537	.03207	.02435	.00388	.000126	0.0417	0.158	.09666	0.3579	0.0616	0.133	.00105	.000716	0.0303	.00627	0.3391	.000707	229	009.01
TEXAS	695337.9622	192407.4026	31303.9662	1.6598	.28737	.44677	.62483	.13666	.026252	7.1366	24.376	.79717	7.7507	6.0655	21.758	.16973	.058705	4.3302	.41977	1.6376	.034736	31959	167.36
UTAH	13962.5192	5426.5379	914.1867	0.0490	.01195	.01292	.01875	.00397	.000618	0.2229	0.725	.02183	0.2719	0.1028	0.691	.00469	.000959	0.1396	.01987	0.3628	.000935	909	011.65
VIRGINIA	5864.6337	2299.1351	374.1107	0.0194	.00256	.00536	.00771	.00165	.000257	0.1172	0.317	.00942	0.1379	0.0761	1.756	.00707	.003665	0.0502	.00845	0.0172	.000395	373	000.00
WASHINGTON	41602.9278	15441.7149	2728.0838	0.1409	.02531	.03033	.05416	.01190	.001575	0.4757	7.125	.06703	0.5801	0.5313	1.903	.01366	.003312	0.3729	.05436	0.1245	.002885	2729	013.75
WISCONSIN	3786.1962	1418.4256	252.5271	0.0131	.00304	.00358	.00502	.00109	.000130	0.0618	0.194	.00552	0.3565	0.0632	0.163	.00171	.000255	0.2365	.00531	0.3113	.000258	249	337.75
WEST VIRGINIA	5017.8361	2329.2613	154.3770	0.0196	.00162	.00579	.02566	.00136	.000736	0.0990	0.217	.01222	0.0513	0.0499	0.282	.00216	.002131	0.0264	.00365	0.0145	.000677	154	000.33
WYOMING	19856.9870	7651.1307	1286.2196	0.0674	.01357	.01856	.02580	.00558	.000848	0.3066	1.008	.03074	0.3686	0.2571	0.858	.00662	.001781	0.1825	.02619	0.2568	.001363	1273	010.19
TOTAL	1941009.2299	714833.6909	117125.8504	6.2162	1.22234	1.73019	2.36983	.50521	.093518	27.1690	91.106	2.93609	30.5336	27.7721	80.476	.62533	.204275	16.2775	2.33456	5.3791	.174128	115017	971.48
EPA REGION																							
I	0.0000	0.0000	0.0000	0.0000	.00000	.00000	.00000	.00000	.000000	0.0000	0.000	.00000	0.0000	0.0000	0.000	.00000	.000000	0.0000	.00000	0.0000	.000000	0	000.00
II	90822.5503	31524.8500	5127.2841	0.2682	.03715	.17491	.10475	.02256	.006001	1.3432	4.150	.13077	1.5019	1.0751	5.536	.02866	.007370	0.7766	.11156	0.2163	.005551	5129	205.76
III	143854.5180	55973.8742	8978.5794	0.4881	.09596	.13764	.17972	.03963	.007962	1.9189	6.938	.23238	2.9676	1.7763	6.370	.06811	.019487	1.1787	.16967	0.6155	.012290	8981	275.63
IV	59969.6940	22467.8983	3991.1529	0.2032	.03093	.05716	.07784	.01752	.001966	0.6485	3.130	.08782	0.9147	0.7808	7.636	.01917	.004076	3.5421	.07981	0.1493	.006106	8976	009.31
V	310341.6960	118744.5939	20188.5687	1.0560	.21434	.29053	.40524	.08751	.013035	4.3650	15.793	.47592	5.2556	3.9602	13.611	.13368	.025956	2.8428	.41265	0.9162	.021268	19977	167.20
VI	903069.3989	316892.0677	50766.6443	2.7146	.56872	.75668	1.01751	.21570	.064551	12.2996	39.296	1.30652	13.6791	0.7067	35.191	.27726	.097531	7.0658	1.00516	2.7083	.056267	50132	405.67
VII	82590.0483	33986.5566	4922.6456	0.2784	.07047	.07800	.09839	.07106	.006764	1.5127	3.695	.14916	1.4498	0.9130	3.694	.03217	.016305	0.6683	.09966	0.2200	.005838	4827	082.23
VIII	63795.0939	24657.9346	4177.1167	0.2192	.05361	.05933	.08674	.01792	.002715	0.9905	3.273	.09857	1.2162	0.8264	2.767	.02191	.006937	3.6147	.08769	0.1368	.006333	4116	957.46
IX	246540.4568	93174.6130	15565.9301	0.9133	.12127	.22926	.31356	.06825	.010728	3.5644	12.181	.37877	4.1766	3.0780	10.609	.08002	.024696	2.1513	.31096	0.7153	.016938	15671	936.17
X	52358.0320	19631.3238	3449.9289	0.1772	.02987	.04970	.04809	.01599	.001796	0.5255	2.672	.07625	0.6586	0.6683	2.765	.01665	.004071	0.6574	.06731	0.1578	.003642	3470	013.75
TOTAL	1941009.2299	714833.6939	117125.8504	6.2162	1.22234	1.73019	2.36983	.50521	.093518	27.1690	91.106	2.93609	30.5336	27.7721	80.476	.62533	.204275	16.2775	2.33456	5.3791	.174128	115017	971.48

* TOTAL INDUSTRY WASTE

TABLE 45

QUANTITY OF POTENTIALLY HAZARDOUS WASTE AND HAZARDOUS CONSTITUENTS
GENERATED BY THE PETROLEUM REFINING INDUSTRY, METRIC TONS/YR.
1 9 8 3

STATE	TOTAL POTENTIALLY HAZARDOUS WASTE*		TOTAL HAZARDOUS CONSTITUENTS DRY BASIS	PHENOL	CN	SE	AS	HG	BE	V	CR	CO	NI	CU	ZN	AG	CD	PB	MO	NH4	PNA	OIL	F
	WET	DRY																					
ALASKA	8193.2389	3244.6811	523.7354	0.0322	.00627	.00922	.01106	.00277	.000172	0.0401	0.329	.00900	0.0597	0.0977	0.291	.00248	.000656	0.0631	.00926	0.0192	.003688	523	300.33
ALABAMA	3230.3305	1278.3443	206.2689	0.0127	.00169	.00363	.00431	.00109	.000067	0.0158	0.130	.00390	0.0235	0.0385	0.116	.00098	.000180	0.0248	.00364	0.0076	.001271	206	300.00
ARKANSAS	7753.8768	3139.9168	410.7765	0.0258	.00316	.00772	.00911	.00215	.000519	0.1214	0.277	.01200	0.1116	0.0775	0.281	.00276	.001165	0.0577	.00797	0.0157	.000596	410	000.00
ARIZONA	901.5292	357.7882	57.7498	0.0035	.00047	.00102	.00120	.00030	.000019	0.0044	0.036	.00109	0.0066	0.0108	0.032	.00027	.000050	0.0070	.00132	0.0021	.000075	58	300.03
CALIFORNIA	221111.3819	94280.7862	13311.4961	0.8655	.12443	.23772	.29235	.06958	.010726	3.6749	8.036	.32951	4.1102	2.5721	8.126	.07578	.021443	1.9451	.27368	0.4930	.017937	13263	314.17
COLORADO	13325.1365	5562.5966	825.6614	0.0516	.00679	.01452	.01808	.00436	.000476	0.1791	0.556	.01844	0.2143	0.1612	0.479	.00467	.000800	0.1208	.01710	0.0312	.001085	826	003.03
DELAWARE	29087.7383	12292.4677	1786.7914	0.1121	.01470	.03140	.03927	.00946	.001062	0.4911	1.203	.04109	0.5919	0.3507	1.061	.01022	.001937	0.2671	.03740	0.0653	.002349	1787	000.00
FLORIDA	4651.7399	1890.8250	305.0744	0.0184	.00249	.00537	.00565	.00161	.000100	0.0234	0.192	.00572	0.0345	0.0568	0.168	.00145	.000260	0.0362	.00534	0.0112	.000401	305	000.00
GEORGIA	1287.8988	511.1261	82.4997	0.0051	.00067	.00145	.00172	.00044	.000027	0.0063	0.052	.00156	0.0094	0.0154	0.046	.00039	.000073	0.0099	.00146	0.0030	.000109	82	000.00
HAWAII	6527.7043	2721.5177	404.8545	0.0253	.00333	.00712	.00888	.00214	.000237	0.0830	0.272	.00906	0.0983	0.0792	0.235	.00231	.000378	0.0595	.00844	0.0168	.000537	404	000.00
ILLINOIS	143157.4945	60920.6049	8806.9261	0.5658	.13422	.15440	.19550	.04550	.006103	2.2603	5.821	.20677	2.7485	1.7224	5.135	.05130	.010566	1.3101	.18103	0.3156	.011471	8755	124.71
INDIANA	83665.4556	35554.1678	5056.7597	0.3201	.04464	.09024	.11071	.02651	.003960	1.3184	3.392	.12361	1.4712	0.9789	3.072	.03318	.007666	0.7391	.10332	0.1864	.006827	5037	308.01
KANSAS	64603.7849	20151.9452	3559.3140	0.2606	.06566	.06778	.07590	.01736	.006414	1.3129	2.746	.11019	1.1491	0.6296	2.612	.02540	.015581	0.4559	.05953	0.1327	.005278	3464	384.13
KENTUCKY	15091.7621	6391.8969	925.8600	0.0582	.00763	.01627	.02044	.00489	.000626	0.2308	0.636	.02177	0.2660	0.1839	0.546	.00558	.000885	0.1466	.02032	0.0338	.001217	926	000.00
LOUISIANA	238744.7585	103724.9268	14217.8662	0.9236	.23736	.25425	.30984	.06663	.015265	4.1318	9.196	.37769	4.4158	2.6750	9.944	.09906	.031790	2.0156	.27353	0.5113	.019139	13920	763.65
MARYLAND	2189.6280	868.9143	140.7495	0.0086	.00114	.00247	.00293	.00074	.000045	0.0107	0.088	.00265	0.0160	0.0261	0.078	.00066	.000124	0.0169	.00249	0.0051	.000183	140	200.00
MICHIGAN	13254.0381	5541.9395	874.1931	0.0517	.00810	.01443	.01811	.00432	.000493	0.1720	0.551	.01840	0.2063	0.1610	0.476	.00470	.000768	0.1215	.01714	0.0299	.001075	874	002.75
MINNESOTA	19058.0892	7671.8913	1116.0603	0.0704	.01248	.01945	.02469	.00581	.003711	0.3006	0.749	.02575	0.3623	0.2193	0.666	.00650	.001152	0.1697	.02362	0.0402	.001465	1116	006.98
MISSOURI	10043.6028	4295.6861	611.8697	0.0386	.00505	.01075	.01372	.00323	.000433	0.1775	0.423	.01477	0.2053	0.1223	0.363	.00376	.000624	0.0974	.01365	0.0224	.000803	612	000.00
MISSISSIPPI	26515.6302	10990.2343	1652.0669	0.1030	.01357	.02905	.03595	.00873	.000897	0.3136	1.099	.03603	0.3791	0.3205	0.952	.00915	.001551	0.2354	.03354	0.0604	.002172	1648	000.00
MONTANA	32389.9397	13772.4016	2044.1593	0.1299	.03601	.03496	.04485	.01034	.001259	0.5182	1.318	.04526	0.6605	0.3951	1.145	.01146	.002081	0.3001	.04127	0.0712	.002561	1999	060.21
NEBRASKA	5014.7757	2140.7144	305.9658	0.0193	.00253	.00538	.00688	.00161	.000221	0.0832	0.213	.00738	0.0969	0.0613	0.192	.00190	.000296	0.0492	.00689	0.0112	.000402	305	020.00
NORTH DAKOTA	5205.8769	2279.5932	322.2807	0.0207	.00586	.00550	.00735	.00162	.000248	0.1018	0.219	.00792	0.1208	0.0466	0.187	.00205	.000313	0.0540	.00736	0.0112	.000403	315	026.63
NEW JERSEY	62340.6646	27030.0246	3712.7390	0.2369	.03263	.06624	.08339	.01946	.003422	1.1592	2.579	.09721	1.2525	0.7366	2.308	.02412	.005616	0.5066	.09232	0.1368	.005036	3498	035.26
NEW MEXICO	6667.8119	3659.0102	335.4064	0.0241	.00636	.00566	.01019	.00167	.000911	0.4199	0.333	.01666	0.4411	0.0896	0.258	.03449	.000479	0.1212	.01543	0.3115	.000620	327	307.12
NEW YORK	10147.4914	4321.6954	619.7369	0.0390	.00513	.01090	.01391	.00328	.000460	0.1645	0.430	.01485	0.1881	0.1239	0.367	.00381	.000557	0.0989	.01386	0.0227	.000816	619	003.03
OHIO	80661.7819	36227.2835	4961.1474	0.3139	.05923	.08662	.10962	.02573	.003407	1.3032	3.317	.11597	1.5496	0.9709	2.896	.02921	.005604	0.7497	.10425	0.1785	.006444	4910	038.86
OKLAHOMA	64971.7888	28182.5083	3969.5219	0.2569	.07591	.04965	.08699	.01978	.003747	1.1145	2.552	.09937	1.2751	0.7541	2.387	.02410	.007086	0.5753	.07803	0.1396	.005157	3967	002.63
OREGON	1287.8988	511.1261	82.4997	0.0051	.00067	.00145	.00172	.00044	.000027	0.0063	0.052	.00156	0.0094	0.0154	0.046	.00039	.000073	0.0099	.00146	0.0030	.000109	82	300.03
PENNSYLVANIA	98855.2260	42187.3746	5900.6857	0.3831	.08187	.10706	.12587	.02997	.006047	1.3372	3.757	.15224	1.3535	1.0967	3.742	.03531	.013957	0.7661	.10592	0.2163	.009128	5812	075.68
TENNESSEE	2929.9935	1212.1497	184.7830	0.0119	.00534	.00305	.00406	.00089	.000120	0.0404	0.113	.00391	0.0556	0.0351	0.099	.00102	.000167	0.0267	.00360	0.0060	.000217	176	009.01
TEXAS	502102.3323	216008.2143	29866.3619	1.9147	.33226	.53890	.65134	.15406	.029480	8.0991	19.805	.79072	9.4674	5.6853	18.866	.18584	.060674	4.2762	.59145	1.1030	.040890	29573	291.98
UTAH	12467.6745	5383.3401	772.6891	0.0493	.01195	.01329	.01741	.00394	.000587	0.2189	0.523	.01867	0.2599	0.1516	0.457	.00479	.000739	0.1247	.01715	0.0272	.000977	759	011.65
VIRGINIA	5233.4770	2281.7406	314.3673	0.0200	.00260	.00552	.00714	.00166	.000244	0.1154	0.221	.00800	0.1323	0.0638	0.199	.00202	.000355	0.0530	.00730	0.0115	.000413	314	000.03
WASHINGTON	46366.0832	19190.8019	2893.4331	0.1812	.03014	.05087	.06268	.01511	.001689	0.5097	1.888	.06315	0.5144	0.5536	1.671	.01586	.003191	0.3988	.05562	0.1051	.003900	2873	313.75
WISCONSIN	3370.9616	1406.9817	213.2222	0.0134	.00307	.00368	.00465	.00110	.000121	0.0407	0.138	.00458	0.0515	0.0411	0.120	.00117	.000195	0.0306	.00426	0.0076	.000270	213	002.75
WEST VIRGINIA	5722.0588	2436.4979	160.6043	0.0243	.00234	.00747	.00719	.00183	.000785	0.1088	0.222	.01339	0.0595	0.0586	0.303	.00259	.002232	0.2337	.00653	0.0168	.002698	163	000.00
WYOMING	32605.4315	13735.4988	1991.0121	0.1257	.02111	.03408	.04360	.01038	.001258	0.5538	1.313	.04605	0.6608	0.3853	1.163	.01125	.002577	0.2881	.06006	0.0722	.002613	1976	010.19
TOTAL	1898193.6169	810756.2019	113554.6665	7.2800	1.40684	2.02912	2.48803	.58041	.102325	30.7632	75.146	2.87360	33.7359	21.7729	69.990	.69295	.203681	16.4492	2.27229	4.1432	.152803	112238	1044.99
EPA REGION																							
I	0.0000	0.0000	0.0000	0.0000	.00000	.00000	.00000	.00000	.000000	0.0000	0.000	.00000	0.0000	0.0000	0.000	.00000	.000000	0.0000	.00000	0.0000	.000000	0	000.00
II	72698.1360	31351.7198	4332.4740	0.2759	.03775	.07714	.09728	.02273	.003862	1.3737	3.009	.11206	1.4406	0.9604	2.675	.02793	.006213	0.6935	.09618	0.1595	.005818	4315	005.26
III	141097.9281	60465.1968	8302.6982	0.5452	.10266	.15392	.18239	.04363	.008183	2.0633	5.492	.21746	2.1541	1.5858	5.350	.05080	.018605	1.1368	.15762	0.3130	.011691	8297	075.59
IV	53637.2952	22264.5671	3356.5528	0.2092	.03140	.05882	.07233	.01764	.001837	0.6303	2.222	.07286	0.7679	0.6502	1.924	.01856	.003116	0.4780	.06789	0.1221	.004387	3361	009.01
V	341967.3106	145322.9699	21076.2879	1.3353	.26174	.36882	.46327	.10997	.014775	5.3953	13.968	.49307	6.3893	4.0936	12.346	.12307	.025951	3.1206	.43364	0.7581	.027462	20939	187.94
VI	819237.5183	356716.5744	48779.9328	3.1460	.65502	.87588	1.06747	.24476	.049902	13.8968	32.164	1.28645	14.7110	9.2812	30.716	.30623	.101196	7.0461	.56651	1.7781	.056192	48226	565.30
VII	79662.1634	35599.1457	4477.1296	0.2985	.07374	.08391	.09649	.02220	.007068	1.5736	2.882	.14133	1.4493	0.8132	3.157	.03134	.016501	0.6030	.09007	0.1663	.006483	4392	384.19
VIII	95796.0090	40733.4332	5955.8027	0.3772	.08170	.10325	.13109	.03065	.003848	1.5717	3.927	.13514	1.9254	1.1598	3.421	.03422	.006510	0.8878	.12292	0.2120	.007639	5873	368.69
IX	228560.6154	97369.0921	13774.1005	0.9764	.12823	.24585	.30244	.07202	.010962	3.7623	9.213	.33964	4.2169	2.6620	8.393	.08735	.021871	2.0116	.28016	0.5069	.018564	13705	036.17
X	55829.1210	22946.4091	3499.6683	0.2185	.03509	.06154	.07526	.01832	.001888	0.5562	2.269	.07460	0.6835	0.6667	2.007	.01873	.003720	0.4719	.06732	0.1273	.006597	3479	013.75
TOTAL	1898193.6169	813756.2019	113554.6665	7.2800	1.40684	2.02912	2.48803	.58041	.102325	30.7632	75.146	2.87360	33.7359	21.7729	69.990	.69295	.203681	16.4492	2.27229	4.1432	.152803	112238	1044.99

* TOTAL INDUSTRY WASTE

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5.0 TREATMENT AND DISPOSAL TECHNOLOGY

5.1 INTRODUCTION AND BACKGROUND

Petroleum refineries generate an estimated 625,000 metric tons per year of waste (dry weight) in the course of distilling crude petroleum and processing of petroleum products. The volume of waste generated as well as the economics of material recovery are determined to a large degree by the type, age, and condition of process units and the market for product "mix." In addition, refineries in different geographic areas encounter widely varying requirements and problems associated with their individual solid waste streams. Treatment and disposal methods used by the industry are contingent upon the nature, concentration, and quantities of waste generated, as well as upon the presumed hazardousness of these materials. They are further affected by geographic conditions, transportation distances, disposal site hydrogeological characteristics, and regulatory agency requirements.

Much of the material wasted by refineries only 20 to 25 years ago has either been eliminated by process changes, is now processed into marketable products, is recycled for reprocessing, or is sold to secondary material processors for extraction of valuable constituents. Noble metal catalysts, caustic solutions containing recoverable quantities of phenolic compounds, and some alkylation sludges reprocessed for sulfuric acid are examples of such waste streams, although these are not within the scope of this study. The types of wastes requiring disposal have been listed and described in Section 4.3 of this report. They include: crude tank bottoms, leaded or non-leaded tank bottoms, API separator sludge, neutralized HF alkylation sludge, kerosene filter clays, once-through cooling water sludge, dissolved air flotation (DAF) float, slop oil emulsion solids, spent lime from boiler feedwater treatment, cooling tower sludge, exchanger bundle cleaning sludge, waste biosludge, storm water silt, fluid catalytic cracker (FCC) catalyst fines, coke fines, lube oil filter clays, spent catalysts, chemical precipitation sludge, vacuum filter or centrifuge cake, and silica gel.

5.2 DATA DEVELOPMENT METHODOLOGY

5.2.1 California Sources

An initial data base was established with information gathered within the State of California, a major oil-producing state, with the help of the following agencies and other sources:

- California State Water Resources Control Board
- Los Angeles Regional Water Quality Control Board, Region 4
- San Francisco Regional Water Control Board, Region 2
- Los Angeles County Engineers Department - Planning Commission on Liquid Waste
- Los Angeles County Sanitation District
- California Solid Waste Management Board
- California Department of Health, Vector Control Section
- Los Angeles Office of United States Department of Transportation
- California State Traffic Department, Hazardous Materials Section
- Public Utilities Commission
- Governmental Refuse Collection and Disposal Association (GRCDA)
- California Vacuum Truck Haulers Association
- Vacuum truck waste hauling firms in Southern California
- Browning-Ferris, Incorporated
- Chemical companies which reclaim materials and by-products from refinery waste material
- California Division of Oil and Gas
- Western Oil and Gas Association
- Private consultants who have specialized in various aspects of petroleum refinery waste disposal

Information obtained through these sources and from knowledgable individuals in private industry proved useful in shaping study methodology and objectives.

5.2.2 General Sources

More generalized data regarding waste management in the remaining states was obtained as follows:

- Solicitation of local, state, and federal regulatory agencies with refineries within their jurisdictional boundaries.
- Contacting refuse haulers and/or disposal firms in various parts of the country to determine regional differences in collection and disposal methods.
- Contacting and/or visiting businesses especially engaged in reclamation or processing of refinery waste materials.
- Enlisting the assistance of the API special Solid Waste Task Force in obtaining the use of the many resources available through its parent organization, the API.
- Examining petroleum refining industry statistics recorded by various governmental agencies, such as the U.S. Bureau of Mines, U. S. Department of Commerce, and the Federal Energy Administration.
- Contacting petroleum refining industry representatives.

5.3 CURRENT TREATMENT AND DISPOSAL TECHNOLOGIES

The various technologies for treatment and disposal of potentially hazardous wastes which are in current use are the following:

5.3.1 Landfilling

Landfilling is presently the most widely used method for disposing of all types of petroleum refinery waste products. The environmental adequacy of this method is contingent not only upon the types and characteristics of generated wastes, but also upon methods of operation and on specific site geologic and climatologic conditions. Of all the land dispoal methods used by the refining industry, perhaps the greatest variations in operations and in site suitability are experienced with landfills. Landfilling operations range from open dumping of construction and refinery debris to controlled disposal in secure landfills in certain Western states. California employs a system of waste categorization and site classification for the regulation of landfill operations which has been used as a model by other states. Since these California waste designations and site classifications will form the basis of all subsequent comparisons and evaluations of landfill operations of the petroleum refining industry, brief descriptions follow.

Waste Categorization:

> Group I Wastes - Wastes which contain toxic and/or hazardous substances with potential chemical reactivities capable of significantly impairing the quality of useable waters. Examples of Group I wastes are: toxic and hazardous fluids from industrial operations, rotary drilling muds containing toxic materials, pesticides, chemicals, and industrial brines.
>
> Group II Wastes - Wastes which contain chemically or biologically decomposable materials but which do not include toxic substances or those capable of significantly impairing the quality of useable waters. Examples are garbage, rubbish, construction and demolition material, sewage treatment sludges, water treatment sludges, ash, and pyrophoric materials.
>
> Group III Wastes - Wastes consisting entirely of non-water soluble, non-decomposable inert solids.

Site Classification:

> Class I Landfill - A disposal facility which has no possibility of discharge to useable waters. Only where natural geology prevents hydraulic continuity between the disposal area and the water can a Class I site lie over a useable ground water area. Run-off and overflow must be contained in the disposal area, and flooding and washout must not occur. All types of wastes may be received, including all designations of hazardous wastes. (A Class I site designation will be used synonymously with the term "secure landfill" throughout this report.) The following criteria are usually used to measure the permeability of naturally occurring soils or equivalent synthetic materials in Class I sites:

(a) Permeability of less than 10^{-8} cm/second.

(b) CL, CH and OH soils per the United Soil Classification system.

(c) Greater than 30 percent by weight passes a No. 200 U.S. Standard sieve.

(d) Liquid limit of greater than 30 percent (ASTM test 423).

(e) Plasticity index of greater than 15 percent (ASTM test D424).

Limited Class I Landfill - A disposal facility which places limitations on the types and amounts of hazardous wastes which may be accepted because of the existing possibility of inundation by flooding more frequently than every 100 years.

Class II - 1 Landfill - A site which can be located over or adjacent to useable groundwater. Containment may be achieved with artificial barriers where natural conditions are insufficient. Protection against floods occurring at 100-year intervals must be provided. Group II and II wastes are accepted, and under special conditions, Group I wastes may also be accepted. The permeability of the natural soil or equivalent artificial barriers should be 10^{-6} cm/second and soil criteria specified for Class I disposal sites should also be fulfilled. Infiltration into adjacent non-water bearing sediments may be allowed if there is no hydraulic continuity with useable water aquifiers.

Class II - 2 Landfill - Sites which allow vertical and lateral continuity with useable groundwater, but which have hydraulic and geologic features which will assure some protection of the quality of useable groundwater underneath or adjacent to the site. These requirements may be based upon soil type, artifical barriers, depth to groundwater, or other factors, for which considerable site-to-site variation may exist.

Class III Landfill - Sites with inadequate protection of water quality, where wastes would enter directly into ground or surface waters. Only Group III wastes may be accepted.

The environmental adequacy of a refinery waste landfill is affected by the following operational and management practices:

(1) The extent of segregation of wastes to prevent mixing of incompatible compounds, such as solids containing heavy metals with acids, or solutions with other wastes which together produce explosions, heat, or noxious gases.

(2) The extent to which liquid or semi-liquid wastes are blended with soil or refuse materials to suitably absorb their moisture content and reduce their fluid mobility within the landfill.

(3) The extent to which acids or caustic sludges are neutralized to minimize their reactivity.

(4) Selection of sites in which the active fill area is large enough to allow efficient truck discharging operations, as well as to assure that blended wastes may be spread, compacted, and covered daily with approximately six inches of cover soil. A site operated in this manner is called a sanitary landfill.

(5) The routing of ground and surface waters around the landfill site and sloping of cover soil to avoid on-site runoff and erosion.

Several on-site refinery landfill operations were observed to employ the best current practices. Special problems were noted in Gulf State refineries where water table levels were near the surface. The major problems associated with most landfill operations, as well as other disposal technologies, were related to soil suitability, facility design, operation, and site development for disposal of potentially hazardous wastes. Many of the landfill sites observed would probably be designated Class II-2.

5.3.2 Landspreading

Landspreading is a relatively inexpensive method of disposal of petroleum refinery wastes, which is being used by a growing number of refineries. The success of landspreading in the warm

Southwestern states has prompted many U. S. refineries in colder climates to experiment with this method of disposal. The majority of refineries contacted which employ landspreading have done so for only one to three years; only a few have a working experience with this process for a longer period of time. One of the first demonstrations of this process was the degradation of refinery oily wastes at Shell Oil Company's Deer Park, Texas refinery several years ago (10).

Considerable research has been done on methods of land disposal of oil skimmed from oceans or beaches, or from accidental truck, train, tank car or barge spills within the country (11-18). Results of this research revealed that landspreading of such material is an economical and efficient disposal method, and it became apparent that this method might be well suited for disposal of refinery-generated wastes as well.

More than 100 species of bacteria, yeast, and fungi, representing 31 genera, are known to attack one or more types of petroleum hydrocarbons (19-25). Straight chain paraffins are the least toxic to soils and plants, while olefins, naphthenes or cycloparaffins, and aromatics are increasingly phytoxic (26). Within each of these groups, smaller molecules are more toxic than are larger molecules (27). Studies indicate that pseudomonous bacteria quickly become the predominant microbial species in the soil (13). Soil moisture appears to be a significant factor in the rate of growth of these bacterial populations; growth is inhibited when the soil moisture content falls below 20 percent. The effect of oil applications to land on soil productivity, soil pH, microbial population changes, and plant toxicity is complex. In temperate regions, changes in soils following contamination by petroleum hydrocarbons are directly related to soil microbial activity, which increases with the addition of oils or gases (28-30). Bacteria quickly degrade the oil using the hydrocarbons as a substrate for their growth. As the degradation process proceeds, the material changes from an oily, odorous black sludge to a dried, cracked, cakey, soot-like material which crumbles easily. The oily characteristics of the sludge are lost after a short period of time. The microbial by-products may change the soil moisture available to plants, reduce iron and aluminum which may accumulate to injure plants, or release nutrients which stimulate plant growth. Various salt marsh species have entirely different tolerances to oil (31, 32).

Soil productivity may actually be enhanced by light applications of oils. Plice observed that petroleum additions of 0.5 to 1 percent by weight produced more luxurious plants than those grown on control plots where no oil was added (28). Carr noted that soybean growth was improved by adding a small amount of oil (20). A number of organic acids from petroleum wastes stimulate plant growth. Weak solutions of napthenic acids increase the root length of cotton, cucumbers, onions, and winter wheat significantly. Even large doses of oil will eventually be degraded by the microorganisms to produce an organically rich and productive soil (20). Heavy applications of oil are often toxic to plants. The volatile fractions, which have great penetrating power, enter plants and seeds and have a narcotic effect on all living organisms. The reduction of manganese, iron, and aluminum to the lower oxidation states increases the toxicity. However, most of the damage to plants appears to result from their inability to obtain sufficient moisture and air due to physical obstruction (28).

The landspreading process is suitable for disposal of almost any oily waste material generated within the refinery. Waste material is pumped into a vacuum truck and conveyed to a disposal site. The oily waste is pumped from the truck through a hand-held discharge hose, which the truckdriver guides in spreading the discharged material as evenly as possible on the assigned land area. The actual depth of application is determined by experience, and varies with the oil composition of the discharge, the soil's moisture and nutrient content, climatologic conditions, and amount of available land. The application rates for oily sludge vary from one to two inches in thickness in the Northwestern U.S. to as much as 3" and 4" in the warmer, subtropical climates of the Southwestern United States. The rate of degradation and disappearance of oil requires between one and six months, depending upon the thickness of the sludge deposit, percent by weight oil content, amount of fertilizer used, and frequency of tilling. Successive loads are handled in the same manner, with each load applied in approximately the same thickness to an immediately adjacent plot. The process is continued until a large area is covered by the oily sludge or waste material. After much of the water has evaporated, a tractor-drawn plow or rototiller is used to break up the oily crust and mix it with a surface layer of soil. The frequency of rototilling, plowing and aeration varies from one location to another. A common practice is to plow the material into the ground to a depth of about six to eight inches and to periodically aerate and blend the oily sludge with the soil. In the Southern United States, a rototiller may go as deep as eight to fourteen inches to entrain air in the subsurface layers of the soil. While some of the hydrocarbons are evaporated as a result of landspreading, there is no noticeable odor, nor is there grounds for concern about spontaneous combustion or flammability.

A Northwestern U.S. refinery which had specific information available calculated that between 1,500 and 2,500 gallons of oily sludge material of approximately 1 to 1.5 percent by weight oil could be disposed of per acre at each application. For this particular geographic area, as many as two or three applications per year appear to be possible. Another West Coast refinery applied approximately 3,600 gallons per acre per year of a heavy sludge of unspecified oil content. Both of these values appear to be average application rates commensurate with individual refineries' specific wastes, method of operation, and local conditions. Some rudimentary laboratory analyses for one refinery indicated that a maximum of 6 percent by weight oil could be applied to their particular soil, and that prescribed amounts of fertilizer should be applied concurrently with the oily sludge. Fertilizer is necessary in order to accelerate the rate of degredation and provide essential nutrients where they are lacking. Oily sludges consist primarily of carbon-hydrogen molecules, and microorganisms using this material as a substrate often require additional nitrogen which is not normally available in sufficient quantities in the soil for their growth. Many refineries do not use fertilizers; most of those that do use only about 25 percent of the stoichiometrically required amount.

Soil characteristics in areas used for landspreading are reported to change with time. In one instance, the initial bentonite clay which had previously dried to a very hard cake changed to a soft, loamy soil, presumably due to increased organic and moisture content. The oily sludge material apparently does not decompose and disappear completely, since a small fraction of the oil remains combined with or interspersed between the individual soil particles. The oil-conditioned soil appears to have a higher moisture content than the native soil. In the case observed, a spontaneous and very luxuriant growth of grass quickly appeared in the area where oil was applied. It grew quickly to a height of two feet, which was far higher than any other plant growth in the area. This grass was also able to grow in dry periods when other plants were unable to survive, providing additional confirmatory evidence for reports in the literature suggesting that at low concentrations oil may act as a plant stimulant (20,28).

A number of refinery-sponsored studies designed to evaluate the landspreading procedure or its effect on plant growth are planned or underway. One refinery is planning to plant agricultural crops on oil spreading areas in an effort to determine mineral uptake and plant ability to grow in this medium. . Alfalfa has been selected to be the first experimental crop because it has deep roots, and water is known to exist lower in the soil at this site. A refinery in Texas is planning to investigate landspreading in order to determine optimum operating procedures. A statistical experimental design using as many as twenty different experimental plots, each measuring approximately twenty feet square (37.16 m^2), is planned to test the main effects and interactions of different oil application rates, aeration frequencies, fertilizer application rates, sludge thicknesses, and oil concentrations. A refinery in Pennsylvania has already initiated a controlled experimental testing program to evaluate the landspreading method. Their well-designed test site employs numerous safeguards and utilizes various upstream and downstream well-monitoring stations. Some early results may already be available. Another East Coast refinery, with the cooperation of the faculty of Cornell University, has conducted an extensive two-year study to evaluate landspreading procedures. A report of the results of their study may already be available.

Up to this time, refineries have been concerned largely with possible oil contamination of ground and surface waters which may result from landspreading. Not many of the petroleum companies have considered other environmental effects which may result from this operation. The real concern is not only the recognized short-term oil problem and incomplete treatment of organic acids and other intermediate by-products, but the long-term implications of trace metal accumulation in the soil over long periods of operation. The problem posed by disposal of heavy metals on or in land is the same for all treatment and disposal technologies. The major difference is a quantitative one, with repeated applications of oily wastes to the same land areas potentially producing greater concentrations of heavy metals than result from other disposal methods. In a confined secure disposal area, these heavy metals and other hazardous organic acids or degradation products do not pose the same level of hazard to the environment. Concentration levels of trace metals and other hazardous components of refinery wastes are shown in Table 39. (Section 4. 6).

An assessment of the environmental adequacy of landspreading for disposal of oily wastes can perhaps best be made in comparison with alternative methods. The desirability of burial of these wastes in a landfill is called into question by the fact that petroleum is not degraded appreciable under anaerobic conditions. If it were, there would be no oil present in the world today. Conversely, hydrocarbon seepages at the earth's surface are not known to exist in large concentrations or to be very old geologically, since aerobic bacteria quickly degrade petroleum fractions to residual waxes and paraffins. Oily fractions deposited in a landfill are merely sequestered for a period of time until they percolate or leach out. It thus becomes important that a landfill be of a secure type to prevent this outward migration of oil and other hazardous constituents.

Even incineration, while destroying most of the organic petroleum fraction, can volatilize certain trace metal constituents and organic compounds, and then release them into the atmosphere, where they can represent a significant and dangerous contaminant. As progressively more oil is removed from refinery waste streams, disposal by incineration will become an endothermic process requiring the application of additional energy to sustain the combustion process. Landspreading does not require the use of external energy to degrade marginal fractions of oily material, since these substances are effectively destroyed through natural aerobic degradation. The problems presented by conservative trace elements once in the ground are very similar whether they are present in residual ash as a result of incineration, in a sanitary landfill, or as a result of landspreading. It would appear, therefore, that landspreading may be emerging as an important method for the disposal of refinery oily wastes. Industry personnel indicate complete satisfaction with related costs, effort, and with the surprising reliability and efficiency of oil degradation. At the present rate of two to three applications annually, the amount of land space actually required is comparatively small.

5. 3. 3. Lagoons, Ponds, Sumps, and Open Pits

Lagoons, ponds, sumps and open pits have been used for many decades by the petroleum refining industry for the disposal of liquid and semi-solid waste. In the past, convenience and easy accessibility rather than environmental considerations dictated disposal site locations. It was thus not uncommon to find sumps and ponds near the refinery process units or at the back of the refinery property. Tank bottoms, slop oil, API separator sludge, and other waste materials were usually allowed to congeal, thicken, percolate, or evaporate in place. Depending on geographic location and climatologic conditions, the extent of weathering, degradation, and volume reduction varied widely. Such sumps were continual receptors of waste materials and with time many of the available sites within the refinery were filled up, the sites simply abandoned or forgotten, and the progressively larger volumes of such waste materials were hauled to nearby offsite locations which were either owned or leased by the refineries.

The expediency of past disposal by simply dumping wastes into lagoons or sumps has turned into a major disposal problem in many parts of the country (33). The demand for elimination of these unsightly sumps has been prompted by many factors, among which are the following: (1) the need for additional land for refinery expansion; (2) increasing land values which demand that land be put to a higher and more profitable use; (3) the envelopment of these lands by urban areas, and the resulting increased potential dangers to people, particularly small children who may stumble into the often unfenced and unprotected lagoon; (4) increasingly stringent regulatory agency requirements; and (5) the desire to eliminate potentially catastrophic situations which may arise as a result of flooding rivers carrying large amounts of petroleum sludge with them. Action is now being taken by a number of states, including California, Oklahoma, Texas, and Pennsylvania, to phase out the use of sumps and lagoons as permanent disposal methods, allowing them to be used only as temporary retention or treatment ponds. They are thus being relegated to use as wastewater treatment units, such as primary and secondary clarifiers, biostabilization or oxidation ponds, or thickening basins. Other uses included evaporation ponds or emergency diversion basins. As wastewater treatment requirements have become more stringent, many simple facultative and anaerobic lagoons have been converted into aeration basins by the addition of mechanical aerators. Because of their simplicity and ease of construction, many of the newer refineries make considerable use of earthen or lined lagoons as primary or secondary sedimentation chambers, aeration basins, oxidation ponds, storm runoff ponds, and emergency oil spill retention basins.

Of the refineries visited, only one made use of a lagoon for the disposal of the majority of its wastes. Two others had recently instituted the use of sumps as a temporary expedient method of disposing of tank bottoms and spilled oily material. Presumably, this material will be scooped up after evaporating and weathering in place, and will be disposed of in a sanitary landfill or by landspreading. Those ponds being used for purposes of equalization, retention, or treatment are periodically emptied with a clam shovel or by vacuum truck, and the material transferred to a permanent disposal facility.

The environmental acceptability of lagoons for any of the prescribed purposes is very much dependent upon the method and materials of construction, specific local hydrogeologic conditions, and the types of waste which are handled. Unfortunately, the potenial for significant contamination of underlying water aquifers from many inadequately lined lagoons, both old and new, is appreciable because of improper location and inadequate safeguards. While many of the units are perfectly acceptable, some attention needs to be paid to insuring that adequate design and construction practices are followed in areas with high water tables, very porous soil, or other adverse conditions.

5.3.4 Leaded Gasoline Sludge Treatment and Disposal

Because organic lead vapors are known to be toxic at very low concentrations (approximately 0.075 to 0.15 mg/m^3, depending on lead compound), special procedures have been developed exclusively for the treatment and disposal of leaded gasoline sludges which accumulate in aviation and motor gasoline storage tanks. A broad variety of lead alkyl additives are utilized in the manufacture of gasoline, the most common being tetraethyl lead. Others are tetramethyl lead, triethylmethyl lead, diethyldimethyl lead, and ethyltrimethyl lead.

During storage, gasoline is exposed to the action of air and diurnal variations in temperature. An unstable gasoline will undergo oxidation and polymerization reactions under these conditions. In the early stages of formation, these polymerization reaction products may remain in solution in the gasoline, but later, further chemical changes cause them to precipitate from solution. This is the material that forms a sludge at the bottom of product storage tanks. The sludge is formed from the olefinic material present which, because of its unsaturated characteristic, is more reactive to the other constituents. The chemical reactions are accelerated by light and heat. It is a chain reaction initiated by the formation of peroxides and catalyzed by the presence of metals, particularly copper, which may be picked up in the refining and handling operations in the refinery. Various trace metals in the gasoline itself may play a part in this reaction. Other contaminants are sulphur, polysuphides, thiophenols, and nitrogen compounds (34).

The survey team encountered two basic procedures for the disposal of leaded-gasoline sludge from gasoline product storage tanks. The procedures were developed and disseminated to the refineries by the two primary manufacturers, the Ethyl Corp. and DuPont. The first procedure is the older of the two and has largely been superseded by an improved method which assures faster and more complete degradation. Both procedures basically involve the construction of a dike surrounding the tank to be cleaned. After the tank contents (except sludge) is pumped to another tank, the remaining sludge is either pumped into the dike for weathering and degradation or is transported to a weathering pad elsewhere within the refinery. It is subsequently rotodisked into the soil or buried on refinery property. These procedures are described in Appendix K. The volume of leaded-gasoline sludge generated is quite small and the frequency of cleaning is subsequently low - on the order of every one to ten years. Even then, the frequency of tank cleaning is dictated more by required tank maintenance than by need for sludge removal.

5.3.5 Incineration

Incineration of semi-solid and solid organic and inorganic refinery-generated wastes requires a special type of system which provides adequate detention times, stable combustion temperatures, sufficient mixing, and high heat transfer efficiency. A fluidized bed is one of the few systems which can satisfy all these criteria. In addition, the fluidized bed of heated solids serves as a heat sink to ignite volatilized hydrocarbons, thereby reducing or eliminating the possibility of creating an extremely dangerous explosive mixture of unburned gaseous hydrocarbons and air. The material to be incinerated can be injected either into the fluidized bed or immediately above it. Refinery wastes known to be incinerated by such systems include spent caustic solutions, API separator bottoms, DAF float, waste bio sludge, and slop oil emulsion solids. Experience has shown that the reaction is self-sustaining if the thermal content of the total wastes incinerated exceeds about 29,000 BTU per gallon. Normal range of operating temperatures is 1300 to 1500 F. Loss of fluidization and plugging of the bed is still a major problem in the operation of these units. The only refinery visited which had an incinerator, mentioned that mechanical problems with the unit were responsible for significant periods of "down" time. Storage pumps and basins had been provided to handle the waste during these periods.

A jointly sponsored American Oil Company and EPA pilot demonstration of the fluidized bed incineration of refinery wastes was conducted during 1969 and 1970 at American Oil Company's (AMOCO) Mandan, North Dakota refinery (*). The results were encouraging enough for the American Oil Company to construct a larger fluidized bed incinerator of improved design at their Whiting, Indiana refinery. This use, coupled with the operation of incinerators by other oil companies, has demonstrated that incineration is a viable treatment and volume reduction method. The use of incinerators, however, appears to be confined to certain parts of the country, i.e., the Midwest, the Great Lakes Region, and the Northeast. There are a multiplicity of reasons for this:

- Hydrogeologic and climatologic conditions preclude the use of methods used successfully in other parts of the country.
- The shortage or high cost of land excludes land intensive treatment and disposal methods.
- Certain reclaimable wastes, because of volume and/or shipping distances, become uneconomical to handle any other way.
- Thermal energy contained in the oily wastes can be used to destroy certain other waste streams not easily treated using any other method.
- Other parts of the country are prevented from using incineration because of air pollution considerations.

Because several of the trace metals under consideration in this study are volatile at temperatures normally encountered during

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(*) Source: EPA Water Quality Office Report No. 12050, 1971 incineration, expensive air emission control devices are required where air pollution emission requirements are stringent. During combustion, organic and metallic materials are converted into a multidue of compounds. Some are partially oxidized or reduced and their structure and properties substantially changed. Others remain chemically unaltered, changing only physically from a solid to a gas. Recent incineration studies have shown that volatilized metals are absorbed to a large degree by fine particulate matter. This material is so fine that many of the conventional air emission control devices remove only a small percentage of it. Presently unspecified quantities of metals and certain gases or combustion products not removed by the air pollution cleaning devices are discharged into the atmosphere each day. Metals of most concern which are emitted from these incinerators (as well as fluid catalytic cracker regenerators) are beryllium, nickel, and vanadium. The solid residue from combustion is sometimes quenched with water, producing a contaminated aqueous waste stream which is routed to the wastewater sewer.. Water scrubbing of incinerator gases produces a similar contaminated waste stream.

Disadvantages associated with the incineration process which were expressed by several refinery managers and plant engineers are the following:

- The process has a high capital cost as well as high reoccurring annual operation and maintenance costs.
- Because of the increased value of oil, as much oil as possible is now extracted from all refinery waste streams. Thus, the thermal value of the various sludges (particularly those that had to be blended with oily wastes) is decreased to such a point that the combustion reactions are either no longer self-sustaining or only marginally so. Continued operation of incinerators thus requires either that valuable oil is left in the various wastes or that additional thermal energy is supplied to the process, further increasing actual operating costs.
- The implementation of increasingly stricter air pollution regulations may mandate extremely expensive and complicated air pollution control devices at some future date.

- More economical and equally efficient treatment and disposal methods are becoming available.

5.3.6 Deep Well Disposal

Subsurface or deep well injection is an ultimate disposal method which originated with the oil and gas extraction industry. Connate brines, separated from the extracted gas and oil, are pumped back into the formations from which the fluid is originally taken, thus restoring the formation pressure and facilitating the extraction of additional gas and oil. Gradually the injection practice has been extended to include a multitude of wastes which would be difficult to dispose of by any other means.

Only one of the sixteen refineries visited practiced deep well injection of waste solutions. Approximately 186.5 million gallons per year are injected, consisting of sulfidic solutions generated by caustic washing of crude cracking and hydrotreating streams, sour water from a hydrotreating unit, brines from the desalter operation, and other weak solutions from crude processing and pretreating. The sulfidic solutions are neutralized with catalytic regenerator flue gas, and before injection into the subterranean formation, all of the solutions are pumped through an upflow mixed media filtration unit consisting of anionic and other unidentified media, possibly sand.

One of the gulf state refineries ships large quantities of refinery waste solutions to a processing and reclamation plant. This firm was of interest because it disposes of certain types of residual wastes by deep well injection. The plant, located in Texas, handles approximately 30,000 barrels per month of petroleum refinery wastes. Approximately 15,000 barrels are oily wastes, and 8,000 barrels are waste acids and caustics. The oil is recovered wherever possible. Economically recoverable materials are separated from these solutions and the residual aqueous and solid wastes treated by activated sludge or incineration. If the treated effluent is relatively innocuous in nature, it is discharged to a receiving surface body of water. Noxious solutions and wastes are injected in the company's single deep well. It was reported that this facility would be shut down in 1975 for undisclosed reasons.

Several refineries in the Southern California area are known to inject waste brines into deep wells. Deep well injection capital and operating costs can be considerable. The future of deep well injection has been clouded by recent legal and regulatory agency decisions (35, 36).

5.3.7 Ocean Disposal

The 1971 Dillingham report (37) for the EPA on ocean disposal of barge-delivered liquid and solid wastes reported that approximately 500,000 tons of refinery wastes have been dumped into the ocean. Many petroleum refineries located in coastal areas discharge their aqueous waste streams after treatment into the ocean through deep water dispersion conduits under National Pollution Discharge Elimination System (NPDES) permits. Sporadic records obtained from Southern California refineries indicated than on random occasions small quantities of barge transported alkaline or acid solutions have been disposed off the California coast. This practice was terminated some time during the late 1960's. It was reported that until recently, certain petroleum refinery wastes in 55 gallon drums were still being dumped in the Gulf of Mexico by one or more gulf state refineries.

The Marine Protection Act of 1972 (PL 92-532) has transferred regulation and control of all ocean dumping from the district office of the U.S. Corps of Engineers to the Environmental Protection Agency. Ocean disposal of certain prescribed hazardous wastes is prohibited, while permits for other less hazardous wastes are becoming increasingly difficult to obtain as alternative methods of ultimate disposal become available. Present trends indicate that ocean disposal will be gradually eliminated.

5.3.8 Special Treatment and/or Disposal Practices

A procedure for reducing the volume of crude tank bottoms which was observed in at least one of the refineries visited is the use of polyelectrolytes. The process is performed prior to cleaning the tanks, at which time any crude oil remaining in the tank is pumped out to the sludge layer and replaced with approximately 5,000 to 6,000 barrels of "Canadian Condensate" or "off-gas" from field wells. The material in the tank is heated with steam and mixed with the crude tank bottoms to a temperature of approximately 130 F. Two kinds of polyelectrolytes are added and the contents mixed for approximately two days. The types of polyelectrolytes and their actual concentrations are determined by laboratory tests. (It has been reported that this procedure does not work well for all types of crude oil.)

The results exceeded expectations. The crude sludge was broken down into a very distinct oil fraction and an underlying clear water fraction, both of which could be separately decanted from the tank. The total quantity of residual sludge which required removal from a 125,000 barrel tank following the use of this treatment amounted to seven barrels. It was found, furthermore, that when this oil fraction was pumped into a different crude oil storage tank, it helped to effect a separation in that tank as well.

The same refinery observed that crude tank bottoms and API separator sludge exposed to alternate freezing and thawing during winter months in an open sump had a considerable layer of oil on the surface the following spring. Subsequent laboratory tests revealed that alternate freezing and thawing does indeed break the emulsions to a considerable degree. The refinery is planning to expand the facility and to perform a controlled study of the method.

Another special practice which was observed in treatment of both liquid and solid wastes is that of chemical fixation. Among the chemical fixation methods which are in use in the petroleum refining industry are the following:

(1) Use of chemical coagulants to create an insoluble precipitate. Only one waste stream in the refineries visited is deliberately treated to produce a chemically inert precipitate. This is the routing of cooling tower blowdown containing hexavalent chromium through the API separator where available sulfides bring about the reduction of hexavalent chromium to trivalent chromium. From the API separator, the now-reduced chromium ion is routed through the spent lime slurry tank where it is further precipitated by lime to chromium hydroxide. The lime sludge containing the precipitated chromium hydroxide is usually removed by vacuum truck.

(2) Sorption of solvent-like hydrocarbons on imbiber beads.

(3) The use of a variety of chemical systems have been devised to overcome the fluidity of certain petroleum wastes. These chemical systems react with various components of the waste to form a semi-solid material which effectively encapsulates or otherwise ties up the harmful constituents. The majority of these methods tend to isolate the material from the environment by either isolating the waste component as a solid mass, drying out the liquid, or achieving some form of chemical bonding or sorption. Chemical fixation or solidifcation is used by a few refineries to solve specific disposal problems, such as the permanent disposal of environmentally unacceptable lagoons filled with API separator bottoms or crude tank bottoms. The Chemfix Process (*) is an example of such a chemical system. It consists of adding metered quantities of reactants to 300 to 500 gallons of waste slurry at intervals of one minute, and mixing to obtain homogeneity. The volume of reactant added to the waste is usually less than ten percent and often below five percent by volume. If cement were used to solidify the same waste, a volume increase of about 100% would typically be required to obtain a solid waste containing the entire liquid portion. The process is continuous and occurs at ambient temperature and pressure.

One of the Texas refineries visited had an accumulation of API separator bottoms "Chemfixed" in February of 1974. This was the only refinery which had material available for observation. Although samples previously tested by the Texas Water Quality Control Board had not produced a significant leachate problem, the Board had nonetheless insisted that the material be placed in a landfill with a large dike around it to prevent surface runoff. The Board also required that approximately two feet of cover dirt be placed over the waste as a precautionary measure, however, this had not yet been done at the time of the survey team visit. The treated material had

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(*) Chemfix Division, the Carborundum Co. Note: Mention of trade names does not constitute endorsement or recommendation by EPA.

the appearance of oil-stained dirt. It had rained heavily the previous day, but there were no visible indications of oil leaching from the material. The Chemfix process can reportedly stabilize materials of up to about 38% solids, using different amounts of proprietary additives. Leaching of various ions is controlled largely by the amounts of silicates added. As the coagulated material dries, the pores reportedly shrink, confining the wastes within the matrix. It is still too early to say exactly how stable these wastes are under actual environmental conditions. To date, approximately 20 million gallons of petroleum refinery wastes consisting primarily of API separator bottoms and crude tank bottoms have been processed using the Chemfix method. Details of this method appear in Appendix L.

5.4 ONSITE VS. OFFSITE DISPOSAL

Offsite treatment and disposal methods employed by the petroleum refining industry are landfilling/dumping (i.e., private, municipal, etc.) and lagooning. Onsite treatment and disposal methods include landfilling/dumping, lagooning, landspreading, deep well injection, and incineration. A summary of onsite and offsite disposal methods used by nineteen refineries appears in Table 46. Information for these tables was obtained primarily from the sixteen refineries visited as well as from the records of three California refineries. For each refinery, waste quantities for each disposal method are given in metric tons. Parenthetical values represent percentages of total refinery waste generated.

At least three of the newer refineries (refineries No. 7, 12 and 13) have not yet instituted routine cleaning of their process units. Data in Table 46 should, therefore, not be construed to suggest that the newer refineries generate lower quantities of waste for comparable production levels and unit processes. Since unit processes employed at these refineries are generally similar to those used in the older refineries within their companies, there is no reason to believe that waste generation rates would differ appreciably for any reasons other than variations in crude oil types or various process or technical innovations which increase or decrease unit charges of processing materials. A record of disposal of wastes generated by four California refineries (refineries No. 14, 17, 18, 19 in Table 46) between the years 1968 and 1973 is tabulated in Appendix M.

TABLE 46

A SUMMARY OF ONSITE AND OFFSITE DISPOSAL METHODS USED BY NINETEEN REFINERIES

No.	Refinery Class	Capacity (bbl/day)	Onsite					Offsite		Solid Waste Generation Rate metric tons/yr 1000 bbl capacity
			Land-filling	Land-spreading	Lagooning	Inciner-ation	Deep Well Injection	Land-filling	Lagooning	
1	IV	180,000						29,134.5 (100)		161.9
2	II	138,000			1,105 (100)					8.0
3	IV	165,000						8,663.7 (100)		52.5
4	II	50,300	13,300 (95.6)	17.6 (0.1)				594.2 (4.3)		276.6
5	III	145,000	237.7 (4.2)	7.3 (0.2)		5,367.9 (95.6)				38.7
6	III	175,000		9,668.9 (91.4)				908.1 (8.6)		60.4
7	III	160,000		2,454.9 (100)			79,652(1)			15.3
8	IV	245,000		2,699.8 (2.3)	113,500.9 (97.7)					474.3
9	II	85,000	544.3 (6.6)	3,311.3 (40.4)				4,350 (53.0)		96.5
10	IV	420,000	91,105.9 (52.2)	32,995.6 (18.9)	687.7 (0.4)			49,608 (28.5)		415.2

(1) Not included in generation value because deep well injection is not a land disposal method.

TABLE 46 (continued)

A SUMMARY OF ONSITE AND OFFSITE DISPOSAL METHODS USED BY NINETEEN REFINERIES

No.	Refinery Class	Capacity (bbl/day)	On-site				Off-site		Solid Waste Generation Rate metric tons/yr 1000 bbl capacity
			Land-filling	Land-spreading	Lagooning	Incineration	Land-filling	Lagooning	
11	III	56,000		566.1 (82.8)			117.9 (17.2)		12.2
12	II	91,000		529.8 (95.9)			22.7 (4.1)		6.1
13	II	96,000	354.7 (32)	753 (68)					11.5
14	IV	165,000					49,504.2 (100)		300.0
15	III	95,000					19,881.2 (23)	66,821.2 (77)	912.7
16	IV	103,000					13,557.1 (17)	67,631.3 (83)	788.2
17	III	77,000					18,122.1 (100)		235.4
18	II	107,000					18,060.4 (100)		168.8
19	III	88,000					3,175.2 (100)		36.1
TOTALS			105,542.7 (16.77)	53,004 (8.42)	115,293.6 (18.32)	5,367.9 (0.85)	215,699.3 (34.27)	134,452.5 (21.36)	
On-Site Total		279.208.4	(44.36)						
Off-Site Total		350,151.8	(55.64)						
		629,360.2							

The distribution of industry wastes according to the various disposal methods is further broken down as follows:

Onsite landfilling	16.8%
Onsite landspreading	8.4%
Onsite lagooning	18.3%
Onsite incineration	0.8%
Offsite landfilling	34.3%
Offsite lagooning	21.4%

Table 47 shows quantities of waste generated by each of 19 refineries, which are listed according to established classification types. These data are provided for comparison purposes.

Comparison of data in Tables 46 and 47 allows evaluation of relationships between waste quantities generated and refinery type, as well as between those quantities and individual refineries. The data in Table 47 indicate a considerable range of values within each refinery classification, as well as an "apparent" general trend of increased waste generation with increasing refinery complexity. It is important to note however that:

(1) At least three of the refineries are relatively new and have not yet started routine cleaning of all process units - resulting in lower than normal waste generation rates.

(2) Refineries No. 15 and 16 are old established plants located close to suitable Class I secure disposal facilities. Their hauling and disposal costs are among the lowest in the country.

(3) Several of the refineries with high generation rates use low API crudes (high viscosity, low API gravity number) and/or have large volumes of water treatment sludges.

(4) Several of the refineries completed extensive plant-wide cleaning operations during the reported time period. Some of the process units will not be cleaned again for 5 to 10 years.

TABLE 47

SOLID WASTE GENERATION RATES BY REFINERY CATEGORY

$$\frac{\text{Metric tons/year}}{\text{1000 bbl capacity}}$$

Type II		Type III		Type IV	
(12)	6.1*	(11)	12.2	(3)	52.5
(2)	8	(7)	15.3*	(1)	161.9
(13)	11.5*	(19)	36.1	(14)	300
(9)	96.5	(5)	38.7	(10)	415.2
(18)	168.8	(6)	60.4	(8)	474.3
(4)	276.6	(17)	235.4	(16)	788.2
		(15)	912.7		
$\bar{x} = 94.6 \pm 110.3$		$\bar{x} = 187.3 \pm 304.68$		$\bar{x} = 365.4 \pm 236.9$	

*New refineries which have not yet started to clean all process units

(5) Removal of peripheral statistical values significantly alters the results and subsequent conclusions.

(6) The mean values and associated standard deviations for the refinery classifications reveal considerable overlapping of the groups.

(7) At least one of the refineries has made a concerted attempt to reduce the amount of solid waste generated through a process of experimentation, process modification, and reuse.

From the tabulation which appears earlier in this section, it is apparent that onsite methods are employed by the petroleum refinery industry to dispose of 44.3% of all generated wastes. Offsite methods account for 55.7% of all wastes. On the basis of disposal practices in the four major refining states of California, Illinois, Louisiana, and Texas, data has been extrapolated to estimate onsite and offsite disposal distribution methods for the years 1973 and 1983. Figures are presented in Table 48 and represent approximate percentages of total quantities of refinery wastes which are disposed of by each major method. Offsite landfilling and offsite lagooning (primarily for evaporation or skimming of oil) are the only two significant offsite disposal methods and represent 34% and 21% respectively of the national total. One refinery employed the landspreading services of a parivate contractor to dispose of certain wastes at an offsite facility, however in proportion to the national total, the quantity was inconsequential, and therefore appears in the table as a zero under offsite landspreading. Landfilling and lagooning represent major onsite disposal methods as well, accounting for approximately 17% and 18% respectively of the national total.

Discussions with refinery and corporate engineering personnel as well as with other industry experts provided the basis for projections for the year 1983 of waste disposal distribution for the various disposal methods. The projected figures indicate a dramatic decrease in the amount of offsite disposal with a concommitant shift to onsite methods, particularly landspreading and landfilling. Lagooning is expected to decrease slightly, and minor increases are expected in incinceration and special onsite disposal practices. Waste destined for offsite disposal is expected to decrease from 56% in 1973 to 27% in 1983, with a large portion of the anticipated decrease being reflected in increased onsite landspreading.

TABLE 48

ESTIMATES OF REFINERY WASTE DISPOSAL METHODOLOGIES UTILIZED FOR THE YEARS 1973 AND 1983

	1973		1983	
Disposal Procedure	Onsite (%)	Offsite (%)	Onsite (%)	Offsite (%)
Landfilling	16.8	34.3	24	20
Lagooning	18.3	21.4	12	7
Incineration	0.8	0	3	0
Landspreading	8.4	0	34	0
Total	44.3	55.7	73	27

This anticipated dramatic decline in offsite disposal in the space of a decade is reflective of the dynamic interactions between emerging environmental regulations and restrictions, the development of new disposal technologies (the most prominent being landspreading and modifications of the coke and fluidized bed incinerator for disposal of various combustible refinery wastes), and the effects of energy shortages which encourage reclamation of oil as well as other unit process and disposal changes. Even before the energy crisis, a variety of factors compelled the refineries to convert to onsite land disposal of their waste. These factors can be delineated as follows:

- The closure of many sumps, lagoons, and dump sites over the last several years has seriously reduced the availability of nearby disposal sites for the disposal of petroleum refinery wastes.
- The present trend is one of increasingly stringent requirements by regulatory agencies surrounding disposal of industrial waste materials to outside municipal or private landfills. Oily wastes are a highly visible and publicized industrial waste, and disposal of petroleum wastes in municipal landfills is gradually being prohibited.
- Regulatory agencies may eventually control the hazardous constituents in petroleum refinery wastes and possibly limit their discharge.
- The costly transporting of large volumes of refinery wastes long distances to federal or state certified secure hazardous waste disposal sites would bring about significant economic and price dislocations to a segment of the industry, and place certain refineries at an immediate disadvantage. The only secure hazardous waste disposal site in one northwestern state, for example, was located some 300 miles from the refineries - a trip at least 10 times the typical offsite hauling distance.
- The emerging stringent water and air emission requirements dictate that increasing volumes of concentrated and possibly hazardous wastes may need to be discharged to the land, since land disposal is not as stringently regulated at the present time.

- No doubt there is some recognition of the legal rights, privileges and precedents afforded by private property laws as they presently exist. This has been observed in a review of the solid waste laws as they apply to private onsite versus public offsite disposal facilities. This legal protection surrounding the use of private property sometimes allows industry to dispose of industrial wastes on their own property without the necessity of permit, monitoring, or supervision and control by regulatory agencies over their disposal operation.

The trend in petroleum companies today is toward self-sufficiency in disposal practices. When building new refineries efforts are made to avoid encumbrance of future regulations by purchasing land areas sufficient to accommodate adequate disposal facilities.

5.5 WASTE HANDLING BY PRIVATE CONTRACTORS

The quantity of refinery-generated waste which is handled by private contractors is closely correlated with offsite disposal quantities, which represent approximately 56% of the total (1973). Hauling/disposal contractors were generally reluctant to divulge information regarding quantities of waste transported, and this information was obtained directly from the refineries. Within the state of California, private waste hauling contractors are required to complete a permit form for each load of industrial waste material transported to a disposal facility. This permit system was included among the provisions of State Senate Bill 598 which was designed in an effort to (1) assure that industrial wastes are disposed of at approved facilities, (2) monitor the quantity of industrial wastes generated, and (3) minimize environmental hazards which result from improper waste disposal management. The hauler must provide the name of the firm generating the waste, the address of the site of waste origin, and the quantity and type of waste. Copies of the permit form including this information are forwarded to the State Water Resources Control Board and to the state disposal site regulating agency. It is the former agency which ultimately regulates the state water quality, and this is achieved through a system of regional boards, each of which is responsible for enforcement of quality standards. State licensure is mandatory for all potential industrial waste haulers, and applications for license are filed with regional offices of the State Water Resources Control Board.

Within the County of Los Angeles, requirements governing industrial waste disposal are stringent. Past problems with ground water contamination resulting from improper disposal practices led to close monitoring by the Los Angeles Department of County Engineers of industrial waste disposal within their area of jurisdiction. For all solid waste material removed to offsite disposal facilities, four major refineries within the County are required to submit monthly reports describing waste types and quantities, point of origin, disposal facility used, and name of waste hauler.

As many as six different waste hauling firms may be simultaneously under contract to a single refinery, although on the average, contracts with three firms are adequate to meet the needs of one refinery. These firms dispose of wastes primarily in sanitary landfills (California Class I site) or in lagoons.

Costs for the services of private waste hauling contractors within the state of California are based upon rates established under Tariff 13 (for vacuum truck hauling operations) by the California Public Utilities Commission. These rates (1974) are $19/hour for a vacuum truck with a capacity of 50-90 barrels, and $21/hour for a truck with a capacity of more than 95 barrels. Both figures include the cost of the driver. Rate adjustments may be made if additional manpower is required, or if overtime periods are involved in completion of waste removal.

A listing of some of the private waste hauling and disposal contractors providing service to petroleum refineries within and without the state of California appears in Appendix N.

5.6 SAFEGUARDS EMPLOYED IN TREATMENT AND DISPOSAL

The environmental adequacy of treatment and disposal methods employed by the petroleum refining industry varies widely, not only with the criteria against which it is assessed, but also with the chemical and physiological characteristics of the discarded waste, their concentrations, their background levels and their chemical and physical mobility in the biological environment. The industry employs various precautionary measures to guard against immediate or future injury to the environment resulting from treatment and disposal practices. Among those commonly encountered during the course of the petroleum refinery field investigations were the following: (1) careful site selection with comprehensive consideration of site geology, soil permeability, soil ion exchange capacity, depth and distance to local groundwater aquifers, and water quality and hydrology;

(2) site utilization and operations, involving adequate use and compaction of impermeable cover materials to prevent excessive infiltration and percolation, sound use of ground sloping to achieve appropriate surface runoff, the use of waste neutralization or degradation prior to final burial, and where applicable, planting of grasses, shrubs and trees for soil stability and water withdrawal by evapo-transpiration; (3) the use of site construction techniques such as the installation of site liners, leachate collection systems, gas migration barriers or venting systems, monitoring wells, protected berms and dikes, and upstream runoff diversion ditches; (4) the use of pretreatment measures such as chemical precipitation or neutralization, dewatering, composting, dilution with municipal refuse or other less hazardous constituents, incineration, and others.

For offsite landfilling, the use of a site classification system is one of the most comprehnsive methods presently employed to safeguard groundwater quality and the surrounding environment. Mandatory minimum requirements for site management and operation are generally monitored by state or local regulatory agencies, and sites typically operate under renewable permits. In California, Texas, and a few other states, petroleum refinery wastes must be placed in a secure Class I or conventional Class II landfill site, and there appears to be a trend toward mandatory offsite monitoring of groundwater quality. Several other states are in the process of enacting enabling legislation which would provide for suitable environmental safeguards.

The major safeguards employed in onsite landfilling are the use of hydrogeologically suitable sites, and the construction of storm runoff diversion ditches, as well as careful adherence to accepted operating practices. Two of the visited refineries used bentonite clays, which are presumed to have high ion exchange capabilities and low permeability, under the onsite landfill areas. Both sites provided for excellent surface drainage surrounding the sites, using a small exposed working surface and an impermeable clay covering mounded in the center to shed runoff water.

Landspreading is a relative innovation in the petroleum refining industry, and its use during the past one to three years has been essentially on a trial basis. The safeguards which are employed in landspreading appear to be limited to the construction of dikes or low-level berms surrounding the spreading surface. The majority of refinery landspreading sites observed had not as yet instituted controls of transportable oil or other hazardous constituents of refinery wastes in surface water runoff. Only one of the experimental facilities employed upstream and downstream monitoring wells for the detection of leachates and analysis of intermediate degradation by-products.

Few of the lagoons and sumps used for disposal of refinery wastes employed adequate safeguards. The majority of lagoons and sumps are constructed from native earth materials, and the only safeguard which was observed was the use of concrete, plastic, or clay liners to reduce or impede the exfiltration of potentially hazardous liquids. This safeguard was employed in few facilities.

Only one example of deep well injection was actually observed during the course of refinery field visits. Two major safeguards were employed by this facility, i.e., those of location and depth selection. A description of construction plans and geological reports confirming the suitability of the site were required by the state regulatory agency. The three disposal wells discharge into unusable saline subterranean formations between 2100 and 4000 feet in depth.

Incineration units employ the use of various types of air pollution scrubber systems as an environmental safeguard. The use of devices for the detection and control of excess oxygen, or of temperature monitoring systems in hearths, stacks, and combustion zones, are additional safeguards sometimes employed. One of the units observed employed specially designed burners and a special injection feed system for controlled burning of the very viscous sludge residues and other types of petroleum refinery wastes. Limited safeguards were employed by the smaller units; even a rudimentary scrubber system was not present in some of the systems.

Special precautions are exercised in the disposal of leaded gasoline sludges and residues. Breathing equipment and tank ventilation systems are used to protect men working within the tanks against toxicity from vapor inhalation. Once the sludge is outside the tank, the vapor concentration is gradually reduced to below the threshold toxicity level. A sump is excavated around the tanks, and entrance to the surrounding diked area is generally prohibited until the vapor concentration has been reduced to levels below twenty parts per million. At those plants where the degraded leaded gasoline sludge is subsequently removed to another part of the refinery for final disposal, the disposal area is surrounded by a locked chainlink fence. The concrete weathering pads employed in the newer disposal procedure are typically enclosed behind locked chainlink fences and elevated one or more feet above the surrounding terrain to minimize the quantity of storm runoff which washes across the pad. The sludge on the concrete slab is contained by a peripheral curbing of at least six inches in height, and the entire slab is sloped to assure drainage to the plant wastewater collection system. All tools such as shovels, rakes, spatulas, hoses, and others, are maintained in a shed within an enclosure and are washed after each application. Gloves and working smocks are also provided within the enclosed area.

Safeguards such as encapsulation in plastic or concrete, burial in steel drums, or leachate collection and treatment specifically for petroleum refinery wastes was not observed. The industry simply believes that this type of treatment and/or handling is not warranted or economically justified. The little material presently discharged to the ocean is currently regulated by the Environmental Protection Agency and permits for ocean disposal represent a safeguard against the use of hazardous practices.

5.7 THREE LEVELS OF TECHNOLOGY FOR TREATMENT AND DISPOSAL OF PETROLEUM REFINERY WASTES

Because of the many factors which affect the ultimate fate of petroleum refinery wastes, the course and extent of the ultimate degradation process is largely speculative. In identifying three levels of technology (defined in Section 1.2) for the treatment and disposal of petroleum refinery wastes, two major criteria have been used. The first is environmental adequacy under varied geologic and climatologic conditions, and the second is the long-term environmental stress on ground water supplies. Tables 49 through 65 contain a description of three levels of treatment and disposal technology associated with each of 17 waste streams generated by the petroleum refining industry. Engineering experience and judgement are combined with a knowledge of basic principles in the assessment of these treatment and disposal technologies. Experienced soil scientists, microbiologists and consulting engineers working the field of petroleum geology and treatment and disposal, were consulted as needed regarding toxicology, epidemiology, chemistry, microbiology, hydrogeology, soil science and sanitary engineering. Appendix O describes the potential of these metals for inter-media transfer.

TABLE 49

LEADED GASOLINE SLUDGE

FACTOR	
Waste Description	Precipitated organic (alkyl) lead compounds in a mixture of gasoline, other destabilized additives, and tank scale (primarily iron oxides).
Generation Rate	Typically 1" - 2" of sludge in tank after 1 - 5 years. Function of tank detention time, temperature variations, and metals which cause destabilization and polymerization of gasoline, resulting in precipitated sludge. Amount disposed annually is about 10,650 metric tons.
Physical & Chemical Properties	Typical organic lead concentration of fresh sludge is 100 - 150 ppm with range of 50 - 200 ppm. This is equivalent to about 0.2 lbs. lbs/ton of sludge. As much as 80% degradation in first several days. Degradation negligible at temperatures below 32° F and in water.
Factors Affecting Hazardousness	Organic lead vapors toxic at very low concentrations (OSHA: 0.075 - 0.15 mg/m^3). Lead, phenols, arsenic, selenium, mercury, cobalt, nickel, zinc, cadmium, and molybdenum which are present in high concentrations are known hazardous constituents.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Methodology	1) Pump tank contents into excavated pit, allow to evaporate and residue to weather for 1 - 4 months, cover contents in pit.	2) Spread sludge to thickness of 2"-4" on concrete pad contained with curbing. Drainage and precipitation runoff to wastewater sewer. Evaporate and weather in place until organic lead concentration is below 20 ppm. Residue to sanitary landfill. 3) Spread sludge in tank diked area or other hydrogeologically secure area. Allow to weather and rotodisc into soil.	2), 3) Same as Level II except for disposal to either a secure landfill or spreading in hydrogeologically safe area.
Estimate of Number of Plants Now using Technology	1) 150 plants (61%)	2) 1 plant (0.4%) 3) 96 plants (39%)	2), 3) Same as Level II
Adequacy	1) Inadequate. In many instances where such pits were uncovered many years later, dangerously high concentrations of organic lead still existed. It is believed that weathering process is incapable of completely degrading organic lead in time periods presently used.	2), 3) Acceptable. Additional degradation at exponentially decreasing rate possible using above surface disking method since weathering process can continue unabated.	2), 3) Same as Level II

TABLE 49 (continued)

LEADED GASOLINE SLUDGE

FACTOR					
Problems	Percolation of alkyl lead in gas carrier occurs during evaporation weathering process. Vapors, while strong, are reported to be below maximum OSHA levels	2), 3)	See above. Vapor concentrations of freshly spread material can be high	2), 3)	Same as Level II
Non-Land Environmental Impact	Solubility of lead compounds change with pH. Mobility increases as organic lead degrades. Possible ground and surface water contamination.	2), 3)	Minimal, if accomplished as indicated above.	2), 3)	Same as Level II
Monitoring and Surveillance	Only monitor rate of alkyl lead degradation during weathering process		Same as Level I		Monitoring wells suggested if water aquifers close to surface or near by
Compatability with Existing Facilities/Processes	Easily adapted		Same as Level I		Same as Level II
Implementation Time	Minimal		Same as Level I		Same as Level II
Energy Requirements	Minimal - transport of sludge and burial or disking into soil		Same as Level I		Same as Level II
COMMENTS:	Concentration of lead in sludge will decrease as alkyl lead concentrations in gasoline are reduced and procedures implemented for addition of lead compounds shortly before shipment from refinery. Only a few refineries dispose of this sludge offsite.				

TABLE 50

COOLING TOWER SLUDGE

FACTOR	
Waste Description	Grey to black silt-like sludge containing high concentrations of several heavy metals, particularly hexavalent chromium and zinc. Salts of both metals are typically added as corrosion inhibitors and water-treating agents. Remaining material is typically from wind-blown dust, corrosion products and process unit leaks.
Generation Rate	Amount generated is usually quite small, about 412 metric tons/yr. Side stream filtration reduces actual quantity even further (filter backwash discharged to wastewater system).
Physical & Chemical Properties	Similar to silt or mud.
Factors Affecting Hazardousness	The heavy metals, hexavalent chromium, zinc, copper, lead, arsenic and selenium which appear in excessive concentrations.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Sludge pumped into vacuum trucks and hauled to landfill	2) Same as Level I except use approved or secure (California classification) Class I site	2) Same as Level II
Estimate of Number of Plants Now Using Technology	200 plants (81%)	19 plants (8%)	Same as Level II
Adequacy of Technology	Unacceptable in most instances.	Adequate	Same as Level II
Problems	High probability that heavy metals migrate easily out of many of these landfills	Minimal	Same as Level II
Non-Land Environmental Impact	Probable heavy metal contamination of ground water	Minimal impact	Same as Level II
Monitoring and Surveillance	Virtually nothing done unless blatant problems exist	Same as Level I	Install monitoring wells. Monitor for heavy metals.
Compatability With Existing Facilities/ Processes	Easily integrated	Same as Level I	Same as Level I
Implementation Time	Minimal time to locate offsite facility, somewhat longer to start on site operation	An acceptable Class I type site may take longer to find. In certain parts of U.S. acceptable natural conditions may not even exist	Same as Level II
Energy Requirements	Minimal - trucking and burial	Same as Level I	Same as Level I

COMMENTS: Reliance on cooling towers with associated problems of hexavalent chromium and other heavy metals can be mitigated by switching to air cooling of unit operations. From 50 to 70% of total cooling capacity of some newer refineries is accomplished with air cooling. Highly probable, that existing refineries with single pass cooling will eventually be required to switch to either recycled water and/or air cooling systems.

TABLE 51

CRUDE TANK BOTTOMS

FACTOR	
Waste Description	An oil-water emulsion containing large quantities of solids and colloidal material which has settled to the bottom of the tank.
Generation Rate	Function of crude source, detention time, and extent of agitation or mixing in tank. Normally 5 - 8 feet of sludge over a period of 1 - 10 years. Annual amount disposed is about 2,414 metric tons.
Physical & Chemical Properties	Varies from reddish-brown to black in color, sweet to sour in odor, and above 1 in density. In general, not flammable at ambient conditions.
Factors Affecting Hazardousness	Heavy metals and oil content.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Sludge vacuum trucked to landfill 2) Spread on land, microbiol action degrades oil	4) Same as Level I, except in secure (California classification) Class I site 3) Same as Level I, except in hydrogeologically secure area and protected by berm to pond any storm runoff	4) Same as Level II 5) Spread in hydrogeologically secure area with adequate safeguards until research areas discussed have been resolved. 7) The following oil recovery process used for at least 1 year in a full scale refinery demonstration. Sludge is mixed with 5000 -6000 bbls of gas condensate and polyelectrolytes, heated and mixed for 2 days at 130°F. Oil and water layers decanted separately. Treated oil pumped to another crude tank where it effected partial breaking of emulsions in that tank as well. Of approximately 8 ft of sludge in 125,000 bbl tank, only 7 bbls of sludge remained for final disposal to sanitary landfills. 6) This oil recovery process discovered by accident during winter of 1973-1974; now undergoing further full scale evaluation. Alternate natural freezing and thawing during winter in open sump breaks emulsions. Oil and water layers decanted separately. Residue landspread.

TABLE 51 (continued)

CRUDE TANK BOTTOMS

FACTOR	LEVEL I	LEVEL II	LEVEL III
Estimate of Number of Plants Now Using Technology	1) 34 plants (14%) 2) 58 plants (23%)	4) 16 plants (6%) 3) 1 plant (0.4%)	4) Same as Level II 7) 1 plant (0.4%) 5) none 6) 1 plant (0.4%)
Adequacy of Technology	1) Inadequate 2) Appears promising but insufficient information (see subsequent comments)	4) Adequate 3) Adequate	4) Same as Level II 5) Adequate 7) Excellent treatment procedure for reducing quantity of sludge requiring disposal and removing a major objectional component (oil) 6) Excellent low cost treatment procedure (applicable to certain parts of U.S.) for breaking emulsions (see (c) above)
Problems	1) Highly probable that oil and/or heavy metals migrating out of landfill 2) There is no long term operating experience with this method. At present, ready accessibility and availability dictate site location at the refinery, not soil suitability, etc. Probable overloading of soil because of too frequent and heavy applications; subsequent percolation of intermediate degradation products. Need to know more about: a) Nature of degradation products b) Best method of operation c) Mobility and buildup of conservative substances	4) Minimal 3) Same as Level I	4) Same as level II 7) Because each crude has different characteristics, need to determine polyelectrolyte type and dosage, condensate quantity and operating levels in laboratory. May not be economical for each crude. Constraints on type of tanks which can be used for this purpose. 6) Method not applicable to all parts of country because of climate. Effectiveness of de-emulsification highly dependent on severity and number of times freezing and thawing occurs 5) Same as Level I
Non-Land Environmental Impact	1), 2) Possible contamination of ground and surface waters from disposal of residues	3), 4) Minimal impact	4), 5), 6), 7) Same as Level II
Monitoring and Surveillance	1), 2) Minimal at present	3), 4) Same as Level I	4), 5), 6), 7) (Use observation wells. Monitor for oil and heavy metals.)
Compatibility with existing facilities/processes	1), 2) No problem	3), 4) Same as Level I	4), 5) Same as Level I 7) Requires suitable tanks 6) Minimal
Implementation Time	1), 2) Minimal	3), 4) Same as Level I	4), 5), 6), 7) Minimal

TABLE 51 (continued)

CRUDE TANK BOTTOMS

FACTOR	LEVEL I	LEVEL II	LEVEL III
Energy Requirements	1), 2) Minimal - transport and disposal	3), 4) Same as Level I	4), 5) Same as Level I 7) Fuel to heat tank contents, residue disposal negligible 6) Minimal - pumping, transporting and disposal

COMMENTS:

There is considerable potential for drastically reducing volumes of crude tank bottoms requiring disposal. With escalating value of oil, increasing cost and distances involved with off-site disposal of this material, and need to conserve space in nearby environmentally acceptable disposal facilities, strong economic incentives exist for recovering oil and reducing waste volumes. Possible procedures are:

a) Mixing crude tank contents to prevent settling. Break emulsion in desalter. Results in small volume of sludge going to wastewater treatment where it receives treatment before emerging as wastewater treatment biosludge. Volume is considerably reduced and oil is essentially removed.

b) Emulsion breaking by natural freezing and thawing.

c) Breaking of emulsions with polyelectrolytes and heat.

d) Physical separation with centrifuges, filters (vacuum, pressure, dutch weave screen), etc.

e) An estimated 5 plants incinerate and landfill the residue, 8 lagoon, and 10 chemically fix the sludge.

TABLE 52

DISSOLVED AIR FLOTATION (DAF) FLOAT

FACTOR	LEVEL I	LEVEL II	LEVEL III
	Prevalent Technology	Best Available Technology	Adequate Health & Environmental Protection
Waste Description	In some refineries, API effluent routed to dissolved air floatation unit for removal of more oil. Brown to black oily sludge.		
Generation Rate	Amount generated annually estimated at 51, 688 metric tons.		
Physical and Chemical Properties	Properties and characteristics of oil		
Factors Affecting Hazardousness	Oil and heavy metals		
Treatment/Disposal Technology	1) Conveyed by vacuum truck to landfill 2) Land spread, oil degraded by microorganisms	3) Same as Level I, except approved or secure (California classification) Class I sanitary landfill 4) Same as Level I, except spread in hydrogeologically secure area.	3) Same as Level II 5) Same as Level II, with additional safeguards (e.g., berm to pond storm runoff, leachate collection drains, etc.)
Estimate of Number of Plants Now Using Technology	1) 15 plants (6%) 2) 12 plants (5%)	3) 4 plants (1.6%) 4) 1 plant (0.4%)	3) Same as Level II 5) None
Adequacy of Technology	1) Inadequate 2) Appears very promising, but insufficient information (see subsequent comments)	3) Adequate 4) Adequate	3) Adequate 5) Adequate
Problems	1) Percolation of contaminants into ground water 2) An emerging technology which appears reliable, economical and quite effective in degrading oil to an innocuous material. However, research still needs to be performed to confirm these initial findings.	3) Minimal 4) Minimized due to confinement	3) Same as Level II 5) Same as Level II
Non-Land Environmental Impact	1), 2) Possible contamination of ground and surface waters	3), 4) Minimal impact if disposed of properly	3), 5) Same as Level II
Monitoring and Surveillance	1), 2) Minimal	3), 4) Same as Level I	3), 5) Should use monitoring wells

TABLE 52 (continued)

DISSOLVED AIR FLOTATION (DAF) FLOAT

FACTOR	LEVEL I	LEVEL II	LEVEL III
Compatability with existing Facilities/ Processes	1), 2) Compatible	3), 4) Same as Level I	3), 5) Same as Level I
Implementation Time	1), 2) Short	3), 4) Same as Level I	3), 5) Same as Level I
Energy Requirements	1), 2) Minimal - trucking and disposal	3), 4) Same as Level I	3), 5) Same as Level I

COMMENTS: The majority of this material is either being landfilled or landspread. A few refineries centrifuge to recover oil. This practice is expected to increase. An estimated 3 refineries use lagoons, 1 incinerates, and 3 use centrifuges with the residue going to landfill.

TABLE 53

EXCHANGER BUNDLE CLEANING SLUDGE

FACTOR			
Waste Description	A mixture of metal scale, coke, particulate matter, and oil removed from the coils and heat transfer surfaces of process heat exchangers to regain original heat transfer efficiency.		
Generation Rate	An estimated 5, 964 metric tons were generated in 1973.		
Physical & Chemical Properties	See Waste Description		
Factors Affecting Hazardousness	Oil and heavy metal content		
	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Landfilling in an approved or secure (California classification) Class I site 2) Landfilling	3) Same as Level I	3) Same as Level I
Estimate of Number of Plants Now Using Technology	1) 64 plants (26%) 2) 85 plants (34%)	3) Same as Level I	3) Same as Level I
Adequacy of Technology	1) Adequate 2) Inadequate	3) Same as Level I	3) Same as Level I
Problems	1) Minimal 2) Percolation of pollutants from the disposal site	3) Same as Level I	3) Same as Level I
Non-Land Environmental Impact	1) Negligible 2) Degradation of water quality	3) Same as Level I	3) Same as Level I
Monitoring and Surveillance	1), 2) Only minimal amount performed	3) Same as Level I	3) Should employ monitoring wells
Compatability with Existing Facilities/ Processes	1), 2) Easily adapted	3) Same as Level I	3) Same as Level I
Implementation Time	1), 2) Negligible	3) Same as Level I	3) Same as Level I
Energy Requirements	1), 2) Small; trucking and burial only	3) Same as Level I	3) Same as Level I

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TABLE 54

SLOP OIL EMULSION SOLIDS

FACTOR			
Waste Description	A mixture of crude and other petroleum fractions recovered from spills and interception points within the refinery which, because of severe contamination, quality, or storage constraints, cannot be used. The slop oil may also be an emulsion similar to crude tank bottoms.		
Generation Rate	Quite variable; estimated to be 19, 596 metric tons/yr.		
Physical & Chemical Properties	Comparable to crude petroleum.		
Factors Affecting Hazardousness	Oil and heavy metals.		
	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Trucked to landfill 2) Spread on land	3) Same as Level I, except approved or secure landfill (i.e. California Class I type site 4) Spread in hydrogeologically secure area with adequate safeguards	3) Same as Level II 4) Same as Level II
Estimate of Number of Plants Now Using Technology	1) 35 plants (14%) 2) 54 plants (22%)	3) 16 plants (6%) 4) 2 plants (0.8%)	3) Same as Level II 4) Same as Level II
Adequacy of Technology	1) Inadequate 2) Insufficient data (see subsequent comments	3) Adequate 4) Adequate	3) Same as Level II 4) Same as Level II
Problems	1) Highly probable that contaminants will leach from landfill 2) Land spreading shows great promise for disposal of all types of oily wastes; however, need to assess: a) best rate of application b) hazardousness of intermediate and final organic degradation products c) fate of heavy metals d) As with most land disposal technologies, hazard minimized if material can be contained indefinitely in disposal area.	3) Minimal 4) Minimal	3) Same as Level II 4) Same as Level II

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TABLE 54 (continued)

SLOP OIL EMULSION SOLIDS

FACTOR	LEVEL I	LEVEL II	LEVEL III
Non-Land Environmental Impact	1), 2) Possible contamination of ground and surface waters	3), 4) Minimal	3), 4) Same as Level II
Monitoring and Surveillance	1), 2) Little or none performed	3), 4) Same as Level I	3), 4) Should install monitoring wells. Monitor for oil and heavy metals
Compatability with existing Facilities/Processes	1), 2) Compatible	3), 4) Same as Level I	3), 4) Same as Level I
Implementation time	1), 2) Minimal	3), 4) Same as Level I	3), 4) Same as Level I
Energy Requirements	1), 2) Small - transport and disposal	3), 4) Same as Level I	3), 4) Same as Level I

COMMENTS:

As is the case with crude tank bottoms and API separator sludges, there is considerable potential for recovery of oil and subsequent reduction in quantities of slop oil requiring disposal. Physical separation processes (such as centrification or filtration) and emulsion breaking procedures are currently being evaluated. Centrification in one refinery had a payback period of 1 - 1.5 years. An estimated 12 plants use lagoons, 5 incinerate, and 3 centrifuge (followed by landfilling of residue).

TABLE 55

ONCE-THROUGH COOLING WATER SLUDGE

FACTOR			
Waste Description	Silt and other settleable solids in raw water supply, leakage from refinery processes being cooled, and corrosion products are settled in clarification basins. Sometimes treated prior to and/or after use. Water supplies containing high silt loads or colloidal organic matter usually treated with alum or other coagulating chemical.		
Generation Rate	Quantities produced vary with refinery and its location. Function of water source, sediment load, season, rate of corrosion, and condition of unit processes. Quantity generated is estimated at 178, 920 metric tons/yr.		
Physical & Chemical Properties	Silt or mud with occluded oil and heavy metals.		
Factors Affecting Hazardousness	Presence of oil and heavy metals such as As, Hg, Mo, Pb, and Se.		
	LEVEL I	LEVEL II	LEVEL III
	Prevalent Technology	Best Available Technology	Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Sludge periodically dredged from clarification basin and landfilled	2) Same as Level I, except in approved or secure landfill (California Class I type site)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	28 plants (11%)	5 plants (2%)	Same as Level II
Adequacy of Technology	Inadequate	Adequate	Adequate
Problems	Probable migration of oil and metals out of landfill	Minimal	Minimal
Non-Land Environmental Impact	Possible leachate contamination of ground and surface waters.	Minimal	Minimal
Monitoring and Surveillance	None observed or reported	None observed or reported	Suggest use of monitoring wells. Monitor for oil and heavy metals
Compatability with Existing Facilities/ Processes	No problem	Same as Level I	Same as Level I
Implementation Time	Minimal	Same as Level I	Same as Level I
Energy Requirements	Minimal - trucking and burial	Same as Level I	Same as Level I
COMMENTS:	The use of single-pass cooling water is expected to decrease considerably as more refineries switch to cooling towers and air cooling, subsequently reducing the volume of water processed and sludge produced. Private contractors typically employed to clean clarification basins.		

TABLE 56

WASTE BIO SLUDGE

FACTOR			
Waste Description	Organic cell material synthesized by micro-organisms during secondary wastewater treatment process which is periodically wasted to maintain steady state conditions.		
Generation Rate	About 0.5 lbs sludge/lb of influent BOD. Estimated quantities for the industry are 11,360 metric tons/yr.		
Physical & Chemical Properties	Watery sludge of organic cell matter which varies typically between 4,000 - 13,000 mg/l of suspended solids, dependent on amount of thickening or dewatering.		
Factors Affecting Hazardousness	Oil and some heavy metals.		
	LEVEL I	LEVEL II	LEVEL III
	Prevalent Technology	Best Available Technology	Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Approved or secure sanitary landfilling (California Class I type site) 2) Land spreading 3) Landfilling	1) Same as Level I 4) Same as Level I, except done in hydrogeologically impermeable area with adequate safeguards	1) Same as Level I 4) Same as Level II
Estimate of Number of Plants Now Using Technology	1) 48 plants (19%) 2) 62 plants (25%) 3) 37 plants (15%)	1) Same as Level I 4) 3 plants (1.2%)	1) Same as Level I 4) Same as Level II
Adequacy of Technology	1) Adequate 2) Insufficient information 3) Inadequate	1) Same as Level I 4) Adequate	1) Same as Level I 4) Same as Level II
Problems	1) Minimal 2) Further research required to verify preliminary findings of this promising methodology. Possible migration of intermediate and final degradation products. 3) Probable migration of oil and metals out of landfill	1) Same as Level I 4) Minimal	1) Same as Level I 4) Same as Level II
Non-Land Environmental Impact	2), 3) Possible leachate contamination of surface and ground waters 1) Negligible	1), 4) Minimal	1), 4) Same as Level II

TABLE 56 (continued)

WASTE BIO SLUDGE

FACTOR	LEVEL I		LEVEL II		LEVEL III	
Monitoring and Surveillance Techniques	1), 2), 3)	Very little done in this area	1), 4)	Same as Level I	1), 4)	Suggest use of monitoring wells
Compatability with Existing Facilities/Processes	1), 2), 3)	Easily integrated	1), 4)	Same as Level I	1), 4)	Same as Level I
Implementation Time	1), 2), 3)	Short	1), 4)	Same as Level I	1), 4)	Same as Level I
Energy Requirements	1), 2), 3)	Small - transportation and disposal	1), 4)	Same as Level I	1), 4)	Same as Level I

COMMENTS:

Approximately 50 refineries use lagoons as part of the treatment/disposal system. Three refineries incinerate. However, as more oil is removed from other waste streams in the future, which now provide thermal energy to maintain combustion temperatures, incineration will become more costly or unfeasible.

TABLE 97

STORM WATER SILT

FACTOR	
Waste Description	Soil, oil, spilled solutions, metals, coke fines and other substances from the refinery grounds are transported by storm runoff to the storm water retention basin where they settle.
Generation Rate	Highly variable. Function of amount of paved area, general plant housekeeping, and layout of collection system. Estimated quantity accumulated is 28,400 metric tons/yr.
Physical & Chemical Properties	Resembles (possibly oily) silt and mud.
Factors Affecting Hazardousness	Oil and heavy metals.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Periodically removed to landfill	2) Same as Level I, except use approved or secure landfill (California Class I type site)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	60 plants (24%)	10 plants (4%)	Same as Level II
Adequacy of Technology	Inadequate	Adequate	Same as Level II
Problems	Probable leaching of contaminants	Minimal	Same as Level II
Non-Land Environmental Impact	Deterioration of ground and surface water quality	Minimal	Same as Level II
Monitoring and Surveillance	Not much done	Same as Level I	Use monitoring wells to compare against background water quality.
Compatability with Existing Facilities/Processes	Compatible, space and topography allowing	Same as Level I	Same as Level I
Implementation Time	3 - 8 months for construction of collection system and retention basin Excavation and disposal about a week depending on basin size.	Same as Level I	Same as Level I
Energy Requirement	Infrequent and minimal--excavation followed by trucking to landfill	Same as Level I	Same as Level I
COMMENTS:	Many of the refineries have plans to install storm runoff collection basins in 1975 and 1976.		

TABLE 58

SPENT LIME FROM BOILER FEEDWATER TREATMENT

FACTOR			
Waste Description	Slurry of spent lime resulting primarily from softening of boiler feed water.		
Generation Rate	Function of raw water hardness, desired water quality, blowdown rate and other boiler operating conditions. Approximately 410, 380 metric tons generated annually.		
Physical & Chemical Properties	A mixture of calcium, magnesium, and other carbonates; hydroxides; silt, organic matter, and water.		
Factors Affecting Hazardousness	Small, heavy metal and oil content.		
	LEVEL I	LEVEL II	LEVEL III
	Prevalent Technology	Best Available Technology	Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Landfilled	2) Same as Level I, except approved landfill	2) Same as Level II
Estimate of Number of Plants Now Using Technology	104 plants (42%)	74 plants (30%)	Same as Level II
Adequacy of Technology	Adequate. Metals effectively held as insoluble precipitates at high pH.	Adequate	Same as Level II
Problems	Minimal hazard posed by lime sludges	Same as Level I	Same as Level I
Non-Land Environmental Impact	Little impact, probably beneficial in municipal landfills since neutralizes organic acids and raises pH	Same as Level I	Same as Level I
Monitoring and Surveillance	None	Same as Level I	Same as Level I
Compatibility with Existing Facilities/ Processes	Compatible	Same as Level I	Same as Level I
Implementation Time	Minimal	Same as Level I	Same as Level I
Energy Requirements	Considerable because of large volume requiring transportation and burial	Same as Level I	Same as Level I
COMMENTS:	The use of hot or cold lime softening vs. ion exchange is an economic and environmental question specific to each refinery. Some refineries have both lime and ion exchange softening.		

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TABLE 59

KEROSENE FILTER CLAYS

FACTOR	
Waste Description	Granular shaped clays, used for filtration of contaminants and particulate matter from "light oil" product streams. Noted for its ability to absorb oil. Some refineries stockpile this material in various locations around the refinery to clean up accidental oil spills, after which it is normally landfilled. Stockpiling serves another purpose in that volatile light hydrocarbons evaporate and oil degrades. Resembles clean beach sand when wasted.
Generation Rate	Average amount wasted annually is about 13,206 metric tons.
Physical & Chemical Properties	Highly absorbent granular clay contaminated with oil fractions and heavy metals.
Factors Affecting Hazardousness	Oil and heavy metal content.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	2) Approved or secure landfill (California Class I type site) 1) Landfill	2) Same as Level I	2) Same as Level I
Estimate of Number of Plants Now Using Technology	2) 53 plants (21%) 1) 23 plants (9%)	2) Same as Level I	2) Same as Level I
Adequacy of Technology	2) Adequate 1) Inadequate	2) Adequate	2) Same as Level II
Problems	2) Minimal 1) Solubility of adsorbed oil and metals after burial is largely unknown	2) Same as Level I	2) Same as Level I
Non-Land Environmental Impact	2) Minimal 1) Potential leaching of oil and metals into ground and surface waters but not thought appreciable	2) Minimal impact	2) Same as Level II
Monitoring and Surveillance	1), 2) Little or none performed	2) Same as Level I	2) Use monitoring wells
Compatability with Existing Facilities	1), 2) No problem	2) Same as Level I	2) Same as Level I
Implementation Time	1), 2) Minimal	2) Same as Level I	2) Same as Level I
Energy Requirements	1), 2) Small - trucking and burial only	2) Same as Level I	2) Same as Level I

TABLE 60

NON-LEADED TANK BOTTOMS

FACTOR	
Waste Description	This waste category includes all petroleum products stored in tanks except slop oil, crude tank bottoms and leaded gasoline sludge. In the waste, in addition to large amounts of the particular petroleum product, are tank scale and other corrosion products from upstream process units.
Generation Rate	If accumulation of sludge was the only reason for cleaning, product tanks would only need to be cleaned perhaps once every 1 - 5 years. Instead, tank maintenance and change of service are the main reasons for more frequent cleaning. The estimated quantity generated is 653,200 metric tons annually.
Physical & Chemical Properties	Very similar to the characteristics of the particular petroleum product, except for additional amounts of such metals as Cd, Cu, Co, Fe, Hg, Mo, Pb, Se, and Zn.
Factors Affecting Hazard	Refined oils and metals.

	LEVEL I Prevalent Technology		LEVEL II Best Available Technology		LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1)	Approved sanitary landfill	3)	Same as Level I, except in secure (California classification) class I site	3)	Same as Level II
	2)	Landspreading	4)	Same as Level I, except in hydrogeologically secure area with a surrounding low level berm to divert storm runoff	5)	Conducted in hydrogeologically secure area (or impermeable shallow basin filled with layer of soil) with storm overflow protection and possibly other safeguards
Estimate of Number of Plants now Using Technology	1)	139 plants (57%)	3)	12 plants (4%)	3)	Same as Level II
	2)	58 plants (23%)	4)	1 plant (.4%)	5)	Same as Level II
Adequacy of Technology	1)	Inadequate	3)	Adequate	3)	Same as Level II
	2)	Promising, but insufficient information (see subsequent comments)	4)	Adequate as long as confined	5)	Adequate
Problems	1)	Petroleum is not degraded anaerobically to any appreciable degree, therefore merely absorbed by soil or refuse, or stored until an exit is found. As with most of the disposal methodologies, the hazard can be effectively negated if the material can be confined.	3), 4)	Same as Level I	3), 5)	Same as Level I

TABLE 60 (continued)

NON-LEADED TANK BOTTOMS

FACTOR	LEVEL I	LEVEL II	LEVEL III
Problems - continued	2) Only several years' experience with this process. Landspreading shows great promise for disposal of all types of oil wastes. However, unless used intelligently with understanding of its limitations, it will fall into disfavor (as has sewage attenuation processes). Research should concentrate on: a) Determining optimum loading rates for complete treatment of all degradation products (e.g., organic acids and other intermediates) b) Fate and rate of accumulation of heavy metals c) Identifying intermediate and final degradation products for possible carcinogenic or toxic substances d) Air pollution e) Site selection criteria		
Non-Land Environmental Impact	1), 2) Possible leachate contamination of water supplies	3), 4) Minimal	3), 5) Same as Level II
Monitoring and Surveillance	1), 2) Almost none performed	3), 4) Same as Level I	3), 5) Install monitoring wells. In general, check for oil and heavy metals
Compatibility with Existing	1), 2) Readily adaptable	3), 4) Same as Level I	3), 5) Same as Level I
Implementation Time	1), 2) Short	3), 4) Same as Level I	3), 5) Same as Level I
Energy Requirements	1), 2) Minimal - transport and disposal only	3), 4) Same as Level I	3), 5) Same as Level I

COMMENTS:

Product tanks, contrary to what would be expected, generate more waste than the combined amount from crude, slop oil, and alkyl lead tank. The exact reason for this is unclear, although not decanting completely or almost down to the sludge layer before cleaning because of possible product contamination may be a major reason. An estimated 22 refineries use lagoons. They appear economical and practical for areas where evaporation rates are high. However, future lagoons should be impermeable and/or constructed only in hydrogeologically secure areas.

TABLE 61

API SEPARATOR SLUDGE

FACTOR	
Waste Description	The API Separator is typically the first unit process in any refinery wastewater treatment scheme. In some systems, it is also tied into the accidental oil spill or emergency oil dump collection system. A considerable diversity of waste streams were observed to be routed to this unit, subsequently influencing sludge generation rates, waste characteristics, and potential hazards. Generally, the sludge is a heavy black oily mud.
Generation Rate	Highly variable. Amount handled is about 31,240 metric tons/year.
Physical & Chemical Properties	The material contains high concentrations of phenols, Cr, Se, Hg, Co, Cu, Zn, Cd, Pb, and Mo.
Factors Affecting Hazardousness	Heavy metals and oil content.

	LEVEL I	LEVEL II	LEVEL III
	Prevalent Technology	Best Available Technology	Adequate Health & Environmental Protection
Treatment/Disposal Methodology	1) Sludge vacuum trucked to landfill	2) Same as Level I except secure landfill (California Class I type site)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	131 plants (53%)	10 plants (4%)	Same as Level II
Adequacy of Technology	Inadequate	Adequate	Adequate
Problems	Leaching of contaminants out of disposal site	Minimal	Minimal
Non-Land Environmental Impact	Possible leachate contamination of surface and ground waters	Minimal	Same as Level II
Monitoring and Surveillance	Little if any performed	Same as Level I	Use monitoring wells
Compatability with Existing Facilities/ Processes	Easily implemented	Same as Level I	Same as Level I
Implementation Time	Short	Same as Level I	Same as Level I
Energy Requirements	Minimal - trucking and disposal	Same as Level I	Same as Level I

COMMENTS: Several refineries employ more than one procedure for disposal of this waste - many are experimenting with landspreading. An estimated 46 refineries landspread, 13 centrifuge or vacuum filter with residue solids landfilled, 25 use lagoons, 5 to 7 incinerate, and 13 use some form of chemical fixation. Lagoons for the most part are being phased out. Landspreading and Oil recovery dewatering by centrification or vacuum filtration is expected to increase.

TABLE 62

LUBE OIL FILTER CLAYS

FACTOR	
Waste Description	Reaction products and traces of acid sludge are removed by adsorption on clay following acid-treating of lubricating oils. The spent clay is removed on a rotary filter as an oil and metal contaminated sludge or cake.
Generation Rate	The amount produced annually is estimated at about 48,848 metric tons.
Physical & Chemical Properties	These natural or activated (pretreated with acid) clays have a considerable affinity for oil. Particle size is about 200 mesh.
Factors Affecting Hazardousness	Oil and metals content.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	2) Landfilling in approved or secure Class I site (California classification) 1) Landfilling	2) Same as Level I	2) Same as Level I
Estimate of Number of Plants Now Using Technology	2) 29 plants (12%) 1) 18 plants (7%)	2) Same as Level I	2) Same as Level I
Adequacy of Technology	2) Adequate 1) Inadequate	2) Same as Level I	2) Same as Level I
Problems	2) Minimal 1) Leachability of adsorbed metals and oil following disposal is unknown	2) Same as Level I	2) Same as Level I
Non-Land Environmental Impact	2) Minimal 1) Potential for contamination of water supplies	2) Impact negligible if proper disposal practices are followed	2) Same as Level I
Monitoring and Surveillance	1), 2) Little or none practiced	2) Same as Level I	2) Employ monitoring wells
Compatability with Existing Facilities/Processes	1), 2) Integrated easily	2) Same as Level I	2) Same as Level I
Implementation Time	1), 2) Minimal	2) Same as Level I	2) Same as Level I
Energy Requirements	1), 2) Small - transport and burial	2) Same as Level I	2) Same as Level I

COMMENTS: At least one major lube manufacturer is exploring the feasibility of regeneration of these spent lube clays. No further information was available. The literature indicates that regeneration is a difficult, complex, and costly process which has only been accomplished on a batch basis.

TABLE 63

FCC CATALYST FINES

FACTOR	
Waste Description	Fine grey powder consisting of aluminum silicate catalyst fines with absorbed heavy metals, primarily vanadium and nickel.
Generation Rate	Function of electrostatic precipitator or wet scrubber removal efficiency, severity of process operation, catalyst abrasion resistance, rate of equilibrium catalyst makeup or removal, and number of stages and efficiency of internal cyclones. Quantity produced is about 29,678 metric tons/year.
Physical & Chemical Properties	See waste description.
Factors Affecting Hazardousness	High concentrations of heavy metals. Be, V, and Ni known to cause respiratory diseases. Silicates cause silicosis. Workers wear protective goggles and gauze masks during transfer operations.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Methodology	1) FCC fines collected by electrostatic precipitator conveyed to landfill in closed refuse containers	2) Same as Level I except use secure Class I landfill (California classification system)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	75 plants (30%)	20 plants (8%)	Same as Level II
Adequacy of Technology	Inadequate	Adequate	Adequate
Problems	Probable leaching of heavy metals	Minimal	Same as Level II
Non-Land Environmental Impact	Possible ground and surface water contamination by leachate	With proper disposal, impact is considerably reduced or eliminated	Same as Level II
Monitoring and Surveillance	Negligible	Same as Level I	Suggest use of monitoring wells
Compatability with Existing Facilities/ Processes	No problem with disposal facilities	Same as Level I	Same as Level I
Implementation Time	Minimal - locate acceptable existing disposal facility. Air pollution control devices already exist	Same as Level I	Same as Level I

TABLE 63 (continued)

FCC CATALYST FINES

FACTOR	LEVEL I	LEVEL II	LEVEL III
Energy Requirements	Minimal for transporting and disposal	Same as Level I	Same as Level I

COMMENTS: Several refineries studying feasibility of FCC fines as alumina cement additive. (Needs to be carefully blended on basis of alumina composition). One waste scavenger recovering aluminum. Could also be future source of vanadium.

TABLE 64

COKE FINES

FACTOR	
Waste Description	Grey-black porous chunks and particle fines from coking operation.
Generation Rate	Occurs as: (1) Spillage during transport and loading of coke. Highly variable, function of equipment used. (2) Clarification of water used to hydraulically jet out coke charge. (3) Stockpiled coke which has been contaminated with earth. (4) Approximately 278 metric tons are generated per year.
Physical & Chemical Properties	Varies from large porous chunks to fine particulates of sintered hydrocarbons of low hydrogen: carbon ratio. Also formed by condensation of polynuclear aromatics.
Factors Affecting Hazardousness	Heavy metals particularly vanadium and nickel, are concentrated in the coke through distillation process.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Methodology	1) Dredged fines or scooped up coke chunks are buried in landfill	2) Same as Level I, except use approved or secure Class I landfill (California Classification system)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	47 plants (19%)	6 plants (2.4%)	Same as Level II
Adequacy of Technology	Inadequate	Adequate	Same as Level II
Problems	Leaching of contaminants	Minimal	Same as Level II
Non-Land Environmental Impact	Possible leachate contamination of ground and surface waters	Minimal	Same as Level II
Monitoring and Surveillance	Little or none performed	Same as Level I	Suggest use of monitoring wells
Compatability with Existing Facilities/ Processes	No problem	Same as Level I	Same as Level I

TABLE 64 (continued)

COKE FINES

FACTOR	LEVEL I	LEVEL II	LEVEL III
Implementation Time	Minimal	Same as Level I	Same as Level I
Energy Requirements	Minimal - dredging or collection, trucking and burial	Same as Level I	Same as Level I

COMMENTS: Coke is a low profit item. Better housekeeping and conveyance procedures could reduce spillage and waste somewhat.

TABLE 65

HYDROFLUORIC ACID ALKYLATION SLUDGE

FACTOR	
Waste Description	Cream-brown slurry of relatively insoluble CaF_2 sludge produced by neutralizing spent hydrofluoric acid used in alkylation with spent lime from water treatment.
Generation Rate	Formation of acid-oil polymer during alkylation process dilutes acid. Regeneration by fractionation keeps acid consumption to between 0.2 to 0.5 lb/bbl of total alkylate produced. Waste sludge is estimated at 7,284 metric tons/yr.
Physical & Chemical Properties	High pH waste (9.5 - 12.9) consisting of relatively insoluble CaF_2. Total fluoride varies from 20,000 - 76,000 ppm.
Factors Affecting Hazardousness	Hydrofluoric acid is extremely dangerous because of its high chemical reactivity. Refinery personnel working with any HF alkylation process units must wear completely self-contained life support system which resembles diving suit. Elaborate washdown procedures following completion of work. Danger is largely gone after neutralization with lime.

	LEVEL I Prevalent Technology	LEVEL II Best Available Technology	LEVEL III Adequate Health & Environmental Protection
Treatment/Disposal Technology	1) Hydrofluoric acid neutralized by mixing with spent lime from water treating. Resultant CaF_2 sludge vacuum trucked to landfill	2) Same as Level I except approved or secure Class I landfill. (California classification system)	2) Same as Level II
Estimate of Number of Plants Now Using Technology	38 plants (15%)	4 plants (1.6%)	Same as Level II
Adequacy of Technology	Probably adequate as long as lime is in excess and contents mixed to assure complete reaction.	Adequate	Same as Level II
Problems	Solubility of CaF_2 under different conditions of disposal is unknown.	Minimal	Same as Level II
Non-Land Environmental Impact	Possible contamination of ground water	Minimal	Same as Level II
Monitoring and Surveillance	Little or none performed	Same as Level I	Suggest use of monitoring wells
Compatability with Existing Facilities/ Processes	Accomplished easily	Same as Level I	Same as Level I
Implementation Time	Minimal	Same as Level I	Same as Level I
Energy Requirements	Minor - mixing, trucking and burial	Same as Level I	Same as Level I
COMMENTS:	Chemical stability of CaF_2 bond coupled with soil attenuation capability should mitigate F threat to ground waters.		

6.0 COST ANALYSIS

6.1 INTRODUCTION

The petroleum refining industry generates a total of 1,756,633 metric tons of waste annually (1974), and hazardous constituents of refinery wastes represent approximately 6% of total refinery industry emissions. Approximately 40% of refinery wastes are managed onsite; 60% are managed offsite. Nearly all waste destined for offsite disposal are hauled by private contractors, and final disposition of the wastes is primarily by landfilling and lagooning. For purposes of this study, the cost to industry for treatment and disposal is based upon the waste generation and practices of a typical 20-year old U.S. refinery with a capacity of 100,000 barrels per day. They are further calculated on the basis of three different levels of technology: Level I - treatment and disposal practices commonly in current use; Level II - environmentally best treatment and disposal practices currently used in the industry; Level III - most environmentally adequate treatment and disposal practices achievable. Industry costs for implementation of each of these levels of technology within the typical refinery are then extrapolated to the entire petroleum refinery industry. These costs have been calculated to include present waste management practices, as well as those projected for 1977 and 1983. Data were obtained directly from industry representatives in the course of refinery visits, from waste treatment and disposal contractors, from state public utility commissions, from the Federal Interstate Commerce Commission, and from available literature. Wherever possible, costs are based on actual installations, or on price quotations from waste treatment and disposal contractors. In the absence of such information, cost estimates are developed on the basis of plant-supplied costs for similar treatment and disposal operations.

6.2 COST RATIONALE AND REFERENCES

All cost estimates are based on fourth calendar quarter 1973 prices. Capital costs include expenditures for the engineering, design purchase, and installation of treatment/disposal facilities, as well as land costs when applicable, buildings, special startup costs, equipment, and contractor profits and contingencies. Annualized capital costs assume a ten-year depreciation schedule, and therefore represent 10%

of total capital investment. Interest costs have been calculated at 10%. Depreciation costs have been calculated on the straight line method and are based upon the useful service life of all treatment and disposal equipment as follows:

Equipment/Material	Estimated Useful Service Life, Yr.
(1) General Process Equipment	10-15
(2) Incineration Equipment	15
(3) Lined Ponds	20
(4) Trucks, Bulldozers, Loaders, & other such materials handling & transporting equipment	10

In view of the extreme variability in land costs, land value has been held constant at $12,350 per hectare (2.471 acres), or approximately $5,000 per acre throughout. In many instances, the market value of land used for waste disposal is reduced because of the limited usage for which it is subsequently available. Cost estimates have therefore assumed land values and capital recovery on the following basis:

(1) Where onsite land requirements are significant and storage and/or disposal of wastes does not affect ultimate market value, the estimated costs reflect only interest on invested capital.

(2) For significant onsite land requirements where ultimate market value and/or availability of land for subsequent use has been seriously reduced, estimates include capital depreciation as well as interest on invested capital.

(3) Offsite treatment/disposal land costs are assumed to be included in contractor's fees and therefore are not added.

The selected land value is further based upon the following estimates: Secure landfilling and landspreading operations requiring special preparation are reflected in a constant land cost of $19,760 per hectare ($8,000 per acre); use of additional special safeguards increases calculated constant land values to $24,000 per hectare (approximately $10,000 per acre).

Annual operating costs, including labor, supervision, materials, maintenance, taxes, insurance, and power and energy are combined with annualized capital costs to give total costs for treatment and disposal operations. Labor and equipment costs are calculated at $10 per hour for a 90 to 100 barrel vacuum truck with an operator, or $20 per hour for the use of a bulldozer or other earthmoving equipment for waste disposal. Labor and supervision for treatment equipment varies from 0 to 0.25 operators/shift at $10 per hour with maintenance ranging from 1% to 4% of the capital costs. Power costs were assumed to be $.03 per killowatt hour. Landfills are assumed to be 25 feet deep with a total volume capacity of 1,089,000 cu. ft. (or 30,818.7 cu. meters) per acre. Landspreading costs assume two applications per year, each of two inches in thickness. The specific gravity of materials disposed of to land is assumed to be 1.0. Equipment rental charges are based on an assumed utilization period and on estimated depreciation, maintenance, and fuel costs for each.

Transportation costs for onsite disposal assume that the use of a 100 barrel vacuum truck requires three man-hours for filling, hauling, and discharge of contents. Transportation costs for offsite disposal are based on the actual number of 100 barrel vacuum trucks arriving at the facility and the average number of man-hours required to complete the disposal procedure in an eight-hour period. Since most refinery-generated wastes are conveyed in a vacuum truck to the disposal site, available disposal cost data is often limited to the invoices of private contractors employed for offsite disposal. Fees typically range from about $3 a ton to $7 per ton, with private disposal rates being generally somewhat higher. Waste hauling firms which provide disposal and/or reclamation services as well as transport services are often able to defray some of the costs of their operations by profits from reclamation of waste materials. Among the major items recovered are oil, metals, and extracted chemicals such as cresols and phenols contained in the caustic solutions. Most reclamation operations concentrate primarily on recovery of oil. Treatment/disposal costs associated with individual refinery waste streams are shown in Tables 66 through 82.

Apparent cost variations for specific wastes are primarily a reflection of differences in transportation hauling distances, differences in disposal technology, type of facility from which the material was collected (closed tank, open basin, dry stockpiles on ground or stationery closed containers ready for hauling), as well as of the physical characteristics of the waste material.

6.3 MANAGEMENT COSTS FOR SPECIFIC WASTE STREAMS

Tables 66 through 82 present detailed costs associated with three levels of technology for treatment and disposal of each of seventeen hazardous waste streams generated within a typical refinery with a capacity of 100,000 barrels per day. Each waste stream represents a certain percentage of the total waste generated within the refinery, and costs are reflective of this quantity. Each of the tables includes the following information:

(1) The quantity in wet and dry weight (metric tons per year) of each potentially hazardous waste as well as of each of its hazardous components.

(2) Treatment and disposal costs associated with present and alternative levels of technology.

(3) Investment costs for land or equipment.

(4) Annual costs for capital, operations, energy and power, and outside contractors.

(5) Unit cost of treatment and disposal (per metric ton of waste, dry weight).

A description of each of these waste streams appears in Section 4.3 of this report.

TABLE 66

COSTS FOR TREATMENT/DISPOSAL

LEADED TANK BOTTOMS

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge, cake

Hazardous Components: MT/yr

Phenols	9.70×10^{-3}	Zinc	1.54×10^{-1}
Selenium	1.23×10^{-4}	Silver	6.54×10^{-5}
Arsenic	1.96×10^{-2}	Cadmium	4.85×10^{-4}
Mercury	4.39×10^{-5}	Lead	4.85×10^{-2}
Cobalt	3.77×10^{-3}	Molybdenum	4.54×10^{-3}
Nickel	2.41×10^{-2}	Benz-A-Pyrene	1.62×10^{-5}
		Oil	15.4

Total Hazardous Stream = 75 MT/yr (dry)
77 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III	II, III
ALTERNATIVE	1	2	3
Investment Costs:			
Land	0	80	0
Material or Equipment	0	1310	0
TOTAL	0	1390	0
Annual Costs:			
Capital	0	139	0
Operating	245	170	130
Energy and Power	5	10	5
Contractor	0	0	0
TOTAL	250	319	135
Cost per Metric Ton of Waste (dry)	3.33	4.25	1.80

---

1. Excavated pit in tank dike area, covered after several months
2. Spread 2" - 4" thick on special concrete weathering pad with runoff control, residue to approved or secure landfill
3. Spread in dike area or other hydrogeologically secure area, allow to weather, then rotodisk into soil

TABLE 67

COSTS FOR TREATMENT/DISPOSAL

COOLING TOWER SLUDGE

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge, slurry

Hazardous Components: MT/yr

Phenols	3.96×10^{-5}	Silver	3.00×10^{-6}
Arsenic	9.72×10^{-5}	Cadmium	3.60×10^{-6}
Chromium	6.65×10^{-3}	Lead	4.56×10^{-4}
Zinc	8.10×10^{-3}	Molybdenum	1.32×10^{-5}
		Oil	0.043

Total Hazardous Stream = 2.9 MT/yr (dry)
12.0 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	226	377
TOTAL	226	377
Cost per Metric Ton of Waste (dry)	77.93	130

---

1. Landfill (offsite)
2. Approved or secure Class I landfill (offsite)

TABLE 68

COSTS FOR TREATMENT/DISPOSAL

CRUDE TANK BOTTOMS

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge, dewatered cake

Hazardous Components: MT/yr

Phenols	2.88×10^{-4}	Silver	3.6×10^{-6}
Arsenic	4.22×10^{-4}	Benz-A-Pyrene	2.2×10^{-6}
		Oil	9.48

Total Hazardous Stream = 17 MT/yr (dry)
20 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I	II	II, III	III	III	III
ALTERNATIVE	1	2	3	4	5	6	7
Investment Costs:							
Land	0	243	389	0	486	318	0
Material or Equipment	0	125	135	0	135	0	0
TOTAL	0	368	524		621	318	0
Annual Costs:							
Capital	0	37	52	0	62	32	0
Operating	0	40	40	0	40	30	20
Energy and Power	0	1	1	0	1	0	125
Contractor	377	0	0	629	0	0	0
TOTAL	377	78	93	629	103	62	145
Cost per Metric Ton of Waste (dry)	22.20	4.59	5.47	37	6.06	3.64	8.53

---

1. Truck to landfill (offsite)
2. Landspreading (onsite)
3. Secure landspreading (onsite)
4. Secure Class I landfill (offsite)
5. Secure landspreading with safeguards
6. Natural freezing and thawing to break emulsion, residue to approved or secure landfill, value of recovered oil reduces cost
7. Polyelectrolytes and heat to break emulsion, residue to approved or secure landfill, almost complete recovery of oil

TABLE 69

COSTS FOR TREATMENT/DISPOSAL

DISSOLVED AIR FLOTATION (DAF) FLOAT

PLANT DESCRIPTION:

Size: 100,000 bbl/day
Age: 20 years
Location: Continental U.S.
Waste Generation: Continuous

HAZARDOUS WASTE STREAM:

Form: Slurry, dewatered cake
Hazardous Components: MT/yr

Phenols	1.31×10^{-2}		
Selenium	4.04×10^{-3}	Silver	5.05×10^{-4}
Mercury	9.29×10^{-4}	Oil	290

Total Hazardous Stream = 364 MT/yr (dry)
2020 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I	II, III	II	III
ALTERNATIVE	1	2	3	4	5
Investment Costs:					
Land	0	142452	0	228000	285000
Material or Equipment	0	23250	0	23250	23250
TOTAL	0	165702	0	251250	308250
Annual Costs:					
Capital	0	16570	0	25125	30825
Operating	0	6369	0	6369	6369
Energy and Power	0	1593	0	1593	1593
Contractor	55987	0	94980	0	0
TOTAL	55987	24532	94980	33087	38787
Cost per Metric Ton of Waste (dry)	153.81	67.39	260.93	90.90	106.56

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1. Landfill (offsite)
2. Landspreading (onsite)
3. Secure Class I landfill (offsite)
4. Secure landspreading
5. Secure landspreading with addtional safeguards

TABLE 70

COSTS FOR TREATMENT/DISPOSAL

EXCHANGER BUNDLE CLEANING SLUDGE

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge

Hazardous Components: MT/yr

Phenols	$1.19\text{x}10^{-3}$	Cadmium	$1.08\text{x}10^{-4}$
Selenium	$2.44\text{x}10^{-3}$	Lead	$6.48\text{x}10^{-3}$
Arsenic	$9.54\text{x}10^{-4}$	Molybdenum	$5.85\text{x}10^{-4}$
Mercury	$1.71\text{x}10^{-4}$	Benz-A-Pyrene	$1.98\text{x}10^{-4}$
Chromium	$2.79\text{x}10^{-2}$	Oil	9.45
Nickel	$1.03\text{x}10^{-2}$		

Total Hazardous Stream = 42 MT/yr (dry)
90 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I	I, II, III
ALTERNATIVE	1	2	3
Investment Costs			
Land	0	15	0
Material or Equipment	0	300	0
TOTAL	0	315	0
Annual Costs:			
Capital	0	32	0
Operating	0	350	0
Energy and Power	0	7	0
Contractor	2835	0	2830
TOTAL	2835		2830
Cost per Metric Ton of Waste (dry)	67.50	9.26	67.38

---

1. Approved or secure Class I landfill (offsite)
2. Landfill (onsite)
3. Approved or secure Class I landfill (offsite)

TABLE 71

COSTS FOR TREATMENT/DISPOSAL

SLOP OIL EMULSION SOLIDS

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Continuous

HAZARDOUS WASTE STREAM:

Form: Sludge, dewatered cake
Hazardous Compenents: MT/yr

Phenols	3.45×10^{-3}	Zinc	5.75×10^{-2}
Selenium	2.30×10^{-4}	Silver	9.2×10^{-5}
Arsenic	1.79×10^{-3}	Lead	3.91×10^{-3}
Mercury	1.35×10^{-4}	Molybdenum	1.15×10^{-3}
Chromium	1.20×10^{-1}	Oil	110
Cobalt	2.30×10^{-3}		

Total Hazardous Stream = 138 MT/yr (dry)
230 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I	II, III	II, III
ALTERNATIVE	1	2	3	4
Investment Costs:				
Land	0	2793	0	4468
Material or Equipment	0	1750	0	1750
TOTAL	0	4543	0	6218
Annual Costs:				
Capital	0	454	0	622
Operating	0	463	0	463
Energy and Power	0	112	0	116
Contractor	4340	0	7230	0
TOTAL	4340	1029	7230	1201
Cost per Metric Ton of Waste (dry)	31.45	7.46	52.39	8.70

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1. Landfill (offsite)
2. Landspreading (onsite)
3. Approved or secure Class I landfill (offsite)
4. Secure landspreading (onsite)

TABLE 72

COSTS FOR TREATMENT/DISPOSAL

ONCE THROUGH COOLING WATER SLUDGE

PLANT DESCRIPTION:

Size: 100,000 bbl/day
Age: 20 years
Location: Continental U. S.
Waste Generation: Continuous

HAZARDOUS WASTE STREAM:

Form: Slurry
Hazardous Components: MT/yr

Phenols	3.36×10^{-3}	Silver	8.40×10^{-4}
Arsenic	9.07×10^{-3}	Lead	9.57×10^{-2}
Mercury	8.57×10^{-4}	Molybdenum	4.20×10^{-3}
		Oil	7.22

Total Hazardous Stream = 1260 MT/yr (dry)
1680 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	31701	52835
TOTAL	31701	52835
Cost per Metric Ton of Waste (dry)	25.16	41.93

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1. Landfill (onsite; contract)
2. Approved or secure Class I landfill

TABLE 73

COSTS FOR TREATMENT/DISPOSAL

WASTE BIO SLUDGE

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Continuous

HAZARDOUS WASTE STREAM:

Form: Slurry, dewatered cake
Hazardous Components: MT/yr

Phenols	2.74×10^{-3}	Silver	1.83×10^{-4}
Mercury	1.10×10^{-4}	Cadmium	1.83×10^{-4}
Chromium	1.83×10^{-1}	Molybdenum	1.52×10^{-3}
		Oil	1.71

Total Hazardous Stream = 80 MT/yr (dry)
610 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I, II, III	I	II, III
ALTERNATIVE	1	2	4
Investment Costs:	0	7419	11872
Land	0	4500	5000
Material or Equipment	0	11919	16872
TOTAL			
Annual Costs:	0	1192	1687
Capital	0	1275	1275
Operating	0	40	40
Energy and Power	19185	0	0
Contractor	19185	2507	3002
TOTAL			
Cost per Metric Ton of Waste (dry)	239.81	31.34	37.52

---

1. Secure Class I landfill (offsite)
2. Landspreading (onsite)
4. Secure landspreading (onsite)

TABLE 74

COSTS FOR TREATMENT/DISPOSAL

STORM WATER SILT

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge

Hazardous Components: MT/yr

Phenols	2.00×10^{-3}	Silver	1.35×10^{-4}
Selenium	4.32×10^{-4}	Cadmium	7.02×10^{-5}
Arsenic	1.48×10^{-3}	Lead	1.43×10^{-2}
Mercury	8.1×10^{-5}	Molybdenum	1.86×10^{-3}
Chromium	9.12×10^{-2}	Benz-A-Pyrene	3.43×10^{-4}
Nickel	2.16×10^{-2}	Oil	9.12
Zinc	6.15×10^{-2}		

Total Hazardous Stream = 200 MT/yr (dry)
270 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Cost:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	5095	8490
TOTAL	5095	8490
Cost per Metric Ton of Waste (dry)	25.47	42.45

---

1. Landfill (offsite)
2. Approved or secure Class I landfill (offsite)

TABLE 75

COSTS FOR TREATMENT/DISPOSAL

SPENT LIME FROM BOILER FEEDWATER TREATMENT

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Continuous

HAZARDOUS WASTE STREAM:

Form: Slurry

Hazardous Components:	MT/yr
Phenols	$1.48\text{x}10^{-2}$
Silver	$3.52\text{x}10^{-3}$
Oil	22.53

Total Hazardous Stream = 2,890 MT/yr (dry)
7,040 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	132,844	221,760
TOTAL	132,844	221,760
Cost per Metric Ton of Waste (dry)	45.96	76.73

---

1. Landfill (offsite)
2. Approved landfill (offsite)

TABLE 76

COSTS FOR TREATMENT/DISPOSAL

KEROSENE FILTER CLAYS

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Continuous

HAZARDOUS WASTE STREAM:

Form: Granular Solids
Hazardous components: MT/yr

Phenols	1.96×10^{-4}	Benz-A-Pyrene	1.66×10^{-4}
Silver	4.90×10^{-5}	Oil	3.43
Cadmium	2.45×10^{-5}		

Total Hazardous Stream = 93 MT/yr (dry)
98 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I, II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	1849	3082
TOTAL	1849	3082
Cost per Metric Ton of Waste (dry)	19.88	33.13

---

1. Landfill
2. Approved or secure Class I landfill

TABLE 77

COSTS FOR TREATMENT/DISPOSAL

NON-LEADED TANK BOTTOMS

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U.S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Sludge
Hazardous Components: MT/yr

Phenols	1.01×10^{-2}	Cadmium	1.79×10^{-3}
Cyanide	4.08×10^{-2}	Lead	1.38×10^{-1}
Selenium	6.70×10^{-2}	Molybdenum	5.14×10^{-2}
Mercury	2.35×10^{-3}	Benz-A-Pyrene	3.35×10^{-3}
Zinc	1.59	Oil	3.59×10^{-3}
Silver	3.35×10^{-3}		

Total Hazardous Stream = 4600 MT/yr (dry)
5590 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I	II, III	II	III
ALTERNATIVE	1	2	3	4	5
Investment Costs:					
Land	0	67990	0	108800	136000
Material or Equipment	0	4000	0	4000	6000
TOTAL	0	71990	0	112800	142000
Annual Costs:					
Capital	0	7199	0	11280	14200
Operating	0	12000	0	12000	12000
Energy and Power	0	32	0	32	32
Contractor	105603	0	176005	0	0
TOTAL	105603	19231	176005	23312	
Cost per Metric Ton of Waste (dry)	22.96	4.18	38.26	5.07	5.70

---

1. Landfill (offsite)
2. Landspreading (onsite)
3. Secure Class I landfill (offsite)
4. Secure landspreading (onsite)
5. Secure landspreading with special precautions

TABLE 78

COSTS FOR TREATMENT/DISPOSAL

API SEPARATOR SLUDGE

PLANT DESCRIPTION:

Size: 100,000 bbl/day
Age: 20 years
Location: Continental U.S.
Waste Generation: Continuous

HAZARDOUS WASTE STREAM:

Form: Sludge
Hazardous Components: MT/yr

Phenols	6.48×10^{-3}	Zinc	1.40×10^{-1}
Selenium	4.70×10^{-4}	Silver	2.58×10^{-4}
Arsenic	2.91×10^{-3}	Cadmium	1.97×10^{-4}
Mercury	1.88×10^{-4}	Lead	8.22×10^{-3}
Chromium	1.18×10^{-1}	Molybdenum	2.35×10^{-3}
		Oil	116.5

Total Hazardous Stream = 220 MT/yr (dry)
470 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II. III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and power	0	0
Contractor	8868	14780
TOTAL	8868	14780
Cost per Metric Ton of Waste (dry)	40.31	67.18

---

1. Landfill (offsite)
2. Secure Class I landfill (offsite)

TABLE 79

COSTS FOR TREATMENT/DISPOSAL

LUBE OIL FILTER CLAYS

PLANT DESCRIPTION:

Size: 100,000 bbl/day
Age: 20 years
Location: Continental U.S.
Waste Generation: Continuous

HAZARDOUS WASTE STREAM:

Form: Thick sludge
Hazardous Components: MT/yr

Phenols	$2.0x10^{-3}$	Cadmium	$4.51x10^{-4}$
Mercury	$1.13x10^{-4}$	Benz-A-Pyrene	$6.27x10^{-5}$
Silver	$3.13x10^{-4}$	Oil	24.45
Selenium	$6.89x10^{-4}$		

Total Hazardous Stream = 344 MT/yr (dry)
627 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	I, II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	11832	19720
TOTAL	11832	19720
Cost per Metric Ton of Waste (dry)	34.39	57.33

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1. Landfill (offsite)
2. Approved or secure Class I landfill (offsite)

TABLE 80

COSTS FOR TREATMENT/DISPOSAL

FCC CATALYST FINES

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Continuous

HAZARDOUS WASTE STREAM:

Form: Dry Powder

Hazardous Components: MT/yr

Phenols	4.39×10^{-4}	Silver	3.76×10^{-4}
Vanadium	5.02×10^{-2}	Lead	1.04×10^{-2}
Nickel	5.03×10^{-2}	Molybdenum	1.25×10^{-3}
		Oil	.439

Total Hazardous Stream = 209 MT/yr (dry)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital		0
Operating	0	0
Energy and Power	0	0
Contractor	3944	6573
TOTAL	3944	6573
Cost per Metric Ton of Waste (dry)	18.87	31.46

---

1. Landfill
2. Approved or secure Class I landfill

TABLE 81

COSTS FOR TREATMENT/DISPOSAL

COKE FINES

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Intermittent

HAZARDOUS WASTE STREAM:

Form: Dry powder
Hazardous Components: MT/yr

Phenols	3.92×10^{-6}	Nickel	1.13×10^{-3}
Vanadium	8.92×10^{-4}	Cadmium	1.96×10^{-6}

Total Hazardous Stream = 1.96 MT/yr (dry)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II, III
ALTERNATIVE	1	2
Investment Costs:		
Land	0	0
Material or Equipment	0	0
TOTAL	0	0
Annual Costs:		
Capital	0	0
Operating	0	0
Energy and Power	0	0
Contractor	36	62
TOTAL	36	62
Cost per Metric Ton of Waste (dry)	18.36	31.63

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1. Landfill (offsite)
2. Approved or Secure Class I landfill (offsite)

TABLE 82

COSTS FOR TREATMENT/DISPOSAL

NEUTRALIZED HF ALKYLATION SLUDGE

PLANT DESCRIPTION:

Size:	100,000 bbl/day
Age:	20 years
Location:	Continental U. S.
Waste Generation:	Intermittant

HAZARDOUS WASTE STREAM:

Form:	Calcium Fluoride Sludge
Hazardous Components:	MT/yr
Phenols	0.2×10^{-4}
Silver	0.4×10^{-6}
Fluoride	1.0×10^{-1}

Total Hazardous Stream = 2170 MT/yr (dry)
4738 MT/yr (wet)

COST OF SOLID WASTE MANAGEMENT:

LEVEL	I	II	III
ALTERNATIVE	1	2	2
Investment Costs:			
Land	0	0	0
Material or Equipment	0	0	0
TOTAL	0	0	0
Annual Costs:			
Capital	0	0	0
Operating	0	0	0
Energy and Power	0	0	0
Contractor	14214	23690	23690
TOTAL	14214	23690	23690
Cost per Metric Ton of Waste (dry)	6.55	10.92	10.92

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1. Neutralize with spent lime and truck to landfill
2. Neutralize with spent lime and truck to secure Class I landfill

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APPENDIX A*

CHARACTERISTICS, OCCURRENCE, AND TOXICOLOGY OF TRACE ELEMENTS AND OTHER IDENTIFIED HAZARDOUS SUBSTANCES IN PETROLEUM REFINERY WASTES

The identification of materials known to be toxic to many life processes if present in sufficient quantity, has guided the rationale of the analytical program. It is assumed that these materials are "potentially hazardous" and may become truly hazardous if disposed of in an unacceptable fashion. Their toxicity is addressed in this appendix. These notes amplify a version of those prepared in a recent report by Pomeroy and Lofy (1). For a fuller treatment of this topic, reference may be made to the Versar Report (2).

AMMONIUM SALTS

Ammonia is a gaseous compound with a formula NH_3.

"Ammonium" refers to the univalent cation NH_4^+. This radical behaves in its inorganic state like any other ionic species, forming a series of salts with the negatively charged acid anions. Substituted organic compounds (quaternary ammonia compounds) are environmentally important (act as algicides, etc.), but are not included in this discussion as they do not occur in petroleum.

Occurrence: Ammonium salts occur quite widely in nature, often associated with the **degradation** of protein in decomposition processes. It forms part of the nitrogen cycle and is important to the associated biosphere. It is readily oxidized and so does not accumulate.

Toxicology: One of the most significant compounds of ammonia is the hydroxide. This is highly caustic and an irritant, which if ingested, causes poisoning. The symptoms of poisoning are due to local irritation which causes severe pain in the mouth, throat, and stomach, with vomiting and collapse from the severity of the gastritis. Ingestion of ammonia solution may cause oedema of the larynx, though this may not develop for an hour or two. Inhalation of ammonia vapor in high concentration causes so severe an irritation of the throat as to produce immediate spasm and closure of the glottis, resulting in asphyxia. High concentrations of vapor are injurious to the lungs and death may result from pulmonary oedma. Ammonia burns have resulted from treating insect bites and stings with the strong solution, or even with the dilute solution, especially if a dressing is subsequently applied.

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*References for Appendix A: p. 218

Ammonia Toxicity and pH: In most biological fluids, ammonia exists in two forms, the relative proportions of which are determined primarily by the pH of the solution. Since toxicity depends on the ammonia which enters the organism, and hence the cell, it is important that the cell membranes be relatively impermeable to one form (ionized ammonia) and the other form (non-ionized) easily passes tissue barriers. Toxicity of ammonium compounds to plants is reduced by lowering the pH with nitric acid. The influence of pH on the toxicity of ammonia has also been studied in fish, parasites, ruminants, dogs, mice, and human subjects. The effect appears to be universally comparable throughout nature. In a medium of low pH ammonia is toxic only in high volumes whereas in a medium of high pH far smaller amounts may be lethal.

Ammonium salts are generally less toxic than ammonium hydroxide. McKee and Wolf (3) report that dogs can ingest 24,000 mg/kg of body weight. Toxicity towards maine life is extremely complex and depends upon pH, the presence or absence of bicarbonate, and other factors.

ARSENIC (As)

Arsenic is a steel-grey, brittle solid with a metallic luster. It sublimes on heating with a characteristic garlic-like odor. On heating in a free supply of air, arsenic burns with a blue flame yielding white fumes of arsenious oxide As_4O_6. All arsenic compounds are poisonous and hence, are potentially hazardous. The element is insoluble in hydrochloric acid and in dilute sulfuric acid. It dissolves readily in dilute nitric acid yielding arsenious oxide, and in concnetrated nitric acid, [illegible] regia, or in a sodium hypochlorite solution forming arsenic acid.

Two series of compounds of arsenic are commonly encountered: (a) the arsenious compounds may be regarded as being derived from the amphoteric arsenious oxide As_4O_6 which yields salts with strong acids, e.g., arsenious chloride $AsCl_3$, or with strong bases, e.g., sodium arsenite $NaAsO_2$; and (b) the arsenic compounds corresponding to the pentoxide

As_2O_6; they are usually salts of the tribastic ortho-arsenic acid, e.g., NaH_2AsO_4 and Na_3AsO_4.

Occurrence: In the earth's crust, arsenic concentrations range from 1 to 13 mg/kg, with an average concentration of about 5 mg/kg (4). In the ocean, the values quoted are around 0.003 mg/l (5), while in fresh water they range from 0.003 to 0.050 mg/l (6).

The U.S. Public Health Service standard for arsenic in drinking water is 0.05 mg/l, while the California standard is 0.01 mg/l. Typical standards for foods are 0.1 mg/l for beverages and 1 mg/kg for foods (7).

In crude oil, arsenic is reported in the range of 0.05-1.0 mg/kg with a median value of 0.26 (8).

Toxicology: The ingestion of 100 to 300 mg of arsenic (as arsenious oxide) is usually fatal to humans, however the toxicity depends upon its chemical state. The body is able to metabolize arsenic, and if ingested in small quantities it is deposited in the hair and fingernails without chronic symptoms appearing.

Toxicity toward fish varies from 1 mg/l to as high as 234 mg/l, while most lower biotic forms are not affected by arsenic up to 30 or 40 mg/l (3).

Radioactive Properties: None

BERYLLIUM (Be)

Beryllium has a greyish metallic luster which melts at 1283C. All the common mineral acids attach beryllium with the exception of cold concentrated nitric acid.

Occurrence: Beryllium is reported at various levels, up to 6 mg/kg in the earth's crust. It is not reported in the sixty most abundant minerals in seawater, and Bowen gives its concentration there as low as 0.0000006 mg/l. In fresh water he quotes less than 0.001 mg/l. It occurs at a concentration of 0.002 mg/kg in some animal tissues.

There are no drinking water standards for beryllium.

Toxicology: Beryllium is very toxic to plants, and also to mammals if injected intravenously. Absorption of beryllium from the alimentary tract is slight (about 0.006% of the ingested) and it is excreted rapidly. This fact, combined with the insolubility of the carbonate accounts for the absence of this element from the drinking water standards.

Radioactive Properties: None

CADMIUM (Cd)

Cadmium is a silvery-white, malleable and ductile metal. It dissolves slowly in dilute hydrochloric and sulfuric acids with the evolution of hydrogen. The best solvent for the metal is nitric acid. Only one series of salts, derived from the oxide CdO, is of chemical importance.

Occurrence: Cadmium occurs in the earth's crust at levels of 0.2 mg/kg (4) while in the ocean it ranges in concentration from 0.001 to 0.003 mg/l (5). Reported concentrations for water supplies range from 0.001 to 0.012 mg/l (6). Foodstuffs contain cadmium at levels of a few tenths mg/kg in cereals, meat, and fish.

The USPHS standard for cadmium in drinking water is 0.01 mg/l, which is identical with the California standard.

In crude oil, cadmium is reported at about 0.03 mg/kg (8).

Toxicology: The ingestion of 10 to 15 mg of cadmium in food or drink can cause nausea. Generally, 5 to 10% of the cadmium taken internally is absorbed from the intestinal tract, while 10 to 40% of cadmium breathed into the lungs in dusts is absorbed. The greatest hazard arises not from acute poisoning but from accumulation over a period of time. The half-life of absorbed cadmium in the human body is reported to be 50 to 130 days. Excessive amounts cause serious and painful osteomalacia. Livestock have been poisoned by vegetation on which airborne cadmium from a smelter had settled. In the Jintsu Valley of Japan, mining wastes carrying cadmium, lead, and zinc so polluted a river that rice crops were damaged and people were poisoned by drinking the water. Two hundred people were severely affected, of which half died. Cadmium was judged to be the principal cause, however the other metals no doubt contributed.

The fatal dose of cadmium for animal life is reported at a range of 0.15 to 0.3 mg/kg body weight, while the tolerable limit for fish is 0.01 to 10 mg/l depending on the test animal, the type of water, temperature, and time of exposure. Cadmium acts synergistically with other substances to increase toxicity (3).

Radioactive Properties: None

CHROMIUM (Cr)

Chromium is a white crystalline metal which is not appreciably ductile or malleable. The metal is soluble in hydrochloric acid yielding the blue chromous chloride $CrCl_2$ if air is excluded, otherwise chromic chloride $CrCl_3$ is formed, and hydrogen is evolved. Dilute sulfuric acid reacts similarly forming chromous sulphate in $CrSO_4$ in the absence of air, and chromic sulphate $Cr_2(SO_4)_3$ in the presence of air. Concentrated sulfuric acid, dilute and concentrated nitric acid induce passivity.

The normal oxide of chromium is the green sesquioxide Cr_2O_3 from which the chromic salts are derived. Chromous salts, corresponding to the oxide CrO, are readily oxidized in air to chromic salts; the former are rarely encountered. An acidic oxide, chromium trioxide CrO_3, which gives rise to the colored chromates and dichromates.

Occurrence: Abundance in the earth's crust is reported in the range 35 to 200 mg/kg, with the metal being relatively concentrated in igneous rocks. In the ocean chromium only occurs at a level of 0.0005 mg/l while the USGS survey (6) showed a general range for surface waters of 0.006 to 0.05 mg/l of hexavalent chromium (trivalent chromium salts are insoluble, and hexavalent salts tend to be reduced).

Both the USPHS and the California standard for hexavalent chromium in drinking water supplies is 0.05 mg/l.

In crude oil, chromium is reported at a median value of 0.008 mg/kg and a range of 0.002-0.017 mg/kg (8).

Toxicology: Chromium is an essential nutrient for animals, being required along with insulin for the metabolism of carbohydrates. The daily requirement for humans is not known, but the amount of chromium in an average diet is of the order of a milligram per day. An excess is rapidly eliminated.

Hexavalent chromium is toxic. Contact with chromates used industrially may cause ulceration of the skin and other membranes. Concentrations high enough to damage the tissues may cause cancer. The drinking water containing hexavalent chromium at a concentration of 10 mg/l has been found to cause nausea, and a slight effect was noted at a concentration of 5 mg/l, but not at 3.5 mg/l. Chromium is not cumulative in the body. Most fish appear to tolerate several mg/l of hexavalent chromium, but various phytoplankters and zooplankters are harmed by fractions of a mg/l.

On the other hand, the only evidence for the toxicity of trivalent chromium that was uncovered in this study, was that reported in fish bioassays, in which it seems likely that a chromic salt used in pure water caused a low pH and held some chromium in solution. Bioassays with aluminum salts give similar results, yet no toxicity is attributed to aluminum in water under ordinary conditions. More tests should be made to ascertain whether there is any hazard of toxicity from trivalent chromium.

Radioactive Properties: None

COPPER (Cu)

Copper is a light red metal, which is soft, malleable, and ductile. It is unaffected by hydrochloric acid and by dilute sulfuric acid, but is readily attacked by dilute nitric acid and by warm concentrated sulfuric acid.

There are two series of copper compounds: Those which may be regarded as derived from cuprous oxide Cu_2O (red), known as cuprous compounds and containing the ion Cu^+, and those similarly derived from cupric oxide CuO (black), known as the cupric compounds and giving rise to the ion Cu^{++}.

Occurrence: Copper is reported in the range of 5 to 200 mg/kg in surface rocks, with the highest concentrations appearing in igneous rocks and shales. In fresh water, it is reported at levels of 0.04 mg/l in rainwater (9) to 0.01 mg/l in surface rivers (10).

Vegetation normally concentrates copper from the environment in varying degrees. On a dry-weight basis, most vegetation contains 1 mg/kg or more of copper, ranging up to about 20 mg/kg. It is concentrated further in the bodies of animals, especially in the liver, where the amount may reach several hundred mg/kg.

Both the USPHS and the California standard for copper in drinking water supplies is 1.0 mg/l.

In crude oil, copper is reported at a median level of 1.32 mg/kg and at a range of 0.13-6.33 mg/kg (8).

Toxicology: Copper is an essential nutirent for plants and animals. It is sometimes added to fertilizers for application to copper-poor soils. There is no evidence that the storing of copper in normal amounts in plants and animals has any harmful effects. However, soluble copper in high concentrations may be damaging to plants. The drinking of water containing 20 mg/l of copper may cause nausea, and larger amounts produce diarrhea.

The concentration of copper that is toxic to fish varies greatly with pH and the concentration of other ions. Sometimes concentrations as low as 0.1 mg/l have been found detrimental, however under most natural conditions no harm results from a concentration of 1 mg/l or less. Concentrations of a few tenths of a mg/l can upset an activated sludge plant, and somewhat larger amounts may affect trickling filters. The anaerobic digestion process is affected only by quite large amounts.

Radioactive Properties: None

COBALT (Co)

Cobalt is a steel-grey, magnetic solid. It dissolves slowly in warm dilute hydrochloric or sulfuric acid, and more rapidly in nitric acid, forming cobaltous compounds, which may be regarded as derived from cobaltous oxide CoO. Two other oxides exist; cobaltic oxide Co_2O_3, corresponding to the extremely unstable cobaltic compounds, and cobaltous cobaltic oxide Co_3O_4. All the oxides of cobalt dissolve in acids yielding cobaltous salts.

Occurrence: Cobalt occurs in shales and igneous rocks in a range of 20-25 mg/kg. In seawater, it is present in a range of 0.0003-0.0005 mg/l, and the USGS survey of surface waters reported a range of 0.001 to 0.005 mg/l. Bowen reports 0.5 mg/kg in vegetation, and 0.03 mg/kg in terrestrial animals (4).

Yen reports crude oil concentrations of .032-12.75 mg/kg, with a median value of 1.71 mg/kg (8).

Toxicology: Cobalt compounds are very toxic to plants and moderately toxic to mammals when injected intravenously. In areas deficient of cobalt in the soil, a typical deficiency disease occurs among ruminant mammals. The maximum safe drinking water level has not been established, but ingestion of 25 mg per day over a period of a week or longer is known to affect the hemoglobin content of the blood. In waters of 1 to 30 mg/l cobalt compounds appear to be toxic toward various plants (3). Aquatic biota are stimulated by levels below 1 mg/l, and poisoned by levels greater than 10 mg/l.

Radioactive Properties: None

CYANIDE

Cyanide is the general name for the --CN radical in its inorganic combinations. "Free cyanide" means hydrocoyanic acid, HCN, and the cyanide ion. In neutral water, free cyanide is almost all HCN, and only in alkaline solutions do substantial amounts of the cyanide ion appear. There are also insoluble metallic cyanides and complex cyanides soluble in the presence of an excess of cyanide, as for example, $NaAg(CN_2)$. Very little cyanide remains in solution in the presence of an excess of metallic ions. HCN is a liquid, boiling at 26C (79 F). It is miscible with water in all proportions.

Occurrence: Unlike the chemical elements which are present on the earth in constant amounts, cynaide is produced and destroyed by both natural and man-made processes. Many species of plant life produce cyanide in small amounts so that it is widely dispersed in the biosphere. It is readily oxidized biologically; therefore, it does not accumulate. The amounts found in the environment represent the balance between input and degradation.

Toxicology: The high toxicity of cyanide is well known. The volatility of HCN makes it especially potent. A concentration of 100 parts per million by volume in air is enough to cause death. However, because it is so soluble in water, low concentrations in solution do not produce dangerous atmospheres.

A concentration exceeding 100 mg/l in solution would be necessary to produce a lethal atmosphere of HCN, even in a closed space. By way of comparison, a solution of 1 mg/l of H_2S is equally dangerous. In the animal body, cyanide is detoxified by conversion to thiocyanate. Thus, it is not cumulative. A daily intake of a few milligrams is believed to be harmless. However, exposure for several hours to concentrations of a few ppm in the air causes irritation of the eyes and respiratory passages.

Fish are much more seriously affected by cyanide in the water, because it causes irritation of the gills and loss of the oxygen-supplying function. Concentrations less than 0.1 mg/l may be fatal.

Radioactive Properties: None

FLUORIDE (F^-)

Fluorine is a toxic gas, which by reduction forms a univalent amin, fluoride. This amin forms a series of metallic salts, commonly referred to as fluorides. Hydrofluoric acid, HF, is a highly toxic and hazardous material.

Occurrence: Fluorine is never found free in nature. It occurs as a constituent of fluospar (calcium fluoride) in sedimentary rocks, and as cryolite (calcium aluminum fluoride) in igneous rocks.

Bowen reports levels of 330-740 mg/kg in rocks, 0-9 mg/l in freshwater, and 1.3 mg/l in sea water (4). Marine plants and land animals tend to concentrate fluorides (as much as 150-500 mg/kg may accumulate in mammalian soft tissues, and 1500 mg/kg in bones).

The USPHS has a range of fluoride standards (0.6-1.7 mg/l) effective for varying average annual temperatures.

Toxicology: Fluorides in sufficient quantity are toxic to humans, with doses of 250 to 450 mg, giving severe symptoms and 4.0 grams causing death. The fatal dose has also been reported as 0.5 gms per kg of body weight and as 2.5 grams.

There are numerous articles describing the effects of fluoride-bearing waters on the dental enamel of children and a few papers pertaining to the skeletal damage. The effects reported in many of these references lead to the generalization that water containing less than 0.9 to 1.0 mg/l of fluoride will seldom cause mottled enamel in children, and for adults, concentrations less than 3 or 4 mg/l are not likely to cause endemic cumulative fluorosis and skeletal effect.

The effects of fluoride in drinking water for terrestrial mammals is analogous to those for humans. General toxicity has been reported (3).

Hamsters	70-80 mg/kg body weight
Daphnia	270 mg/kg
Esheria Coli	180 mg/l
Protozoa/Rosifen	1000-1700 mg/l

LEAD (Pb)

Lead is a bluish-grey metal with a density of 11.48. It is readily dissolved by dilute nitric acid.

With concentrated nitric acid, a protective film of lead nitrate, which is insoluble in this acid, prevents complete solution. Dilute hydrochloric acid and dilute sulfuric acid have little action due to the formation of protective films of lead chloride and sulfate, respectively. Lead is both divalent and tetravalent. In addition to forming plumbous and plumbic salts, it also forms plumbites and plumbates.

Occurrence: Lead is reported in the range of 7-20 mg/kg for its occurrence in the earth's crust (4). In water, levels of 0.00003 mg/l are reported in the ocean (5), while a range of 0.006 to 0.050 mg/l was reported in surface fresh waters (6).

Published findings on lead in vegetation show a wide range; values are generally lower in fruits and seeds and higher in the roots and outer leaves. In edible parts the amounts are generally a few tenths of a mg/kg. The concentration of lead found in meats appears to be similar or somewhat lower than in vegetation.

Both ths USPHS and the California drinking water standard for lead is 0.05 mg/l.

Yen reports lead at a median level of 0.24 mg/kg in crude oil, and a range of 0.17-0.31 mg/kg (8).

Toxicology: Lead serves no useful function in plant or animal bodies, but it is a serious hazard to health because it is cumulative. It is believed that chronic toxicity can result from a daily intake of 0.6 mg per day. By contrast, 10 mg per day of arsenic or of cyanide would not be harmful. Lead is lethal for fish in concentrations of a few tenths of a milligram per liter, and at 0.1 mg/l in soft water.

Radioactive Properties: Natural lead is composed of four isotopes with atomic weights of 204, 206, 207 and 208. The latter three are the decay products of the radioactive compounds. The relative abundance of these isotopes are 1.48, 23.6, and 52.3%, respectively. Lead 204 is radioactive, decaying by alpha radiation with a half-life of 1.4×10^{19} years, and if isolated is an extremely hazardous material.

MERCURY (Hg)

Mercury is a silvery-white, liquid metal at ordinary temperatures, and has a density ($d_{4^\circ}^{0^\circ}$) of 13.595. It is unaffected by treatment with dilute hydrochloric or dilute sulfuric acid, but reacts readily with nitric acid.

Mercury forms two series of salts. The mercurous compounds and the mercuric compounds.

Occurrence: Mercury in elemental form is reported in the range of 0.03 to 0.1 mg/kg in the earth's crust. In the oceans it has been reported at levels of 0.00003 mg/l (5), and the USGS survey reported a range of 0.0001 to 0.004 mg/l in surface waters (6). Generally, 0.001 to 0.01 mg/kg occurs in vegetation, while some meats and fish carry up to 0.3 mg/kg and occasionally, 1.0 mg/kg.

The USPHS does not currently set s drinking water standard for mercury, however the California standard is 0.005 mg/l.

Yen reports the crude oil median concentration of mercury at 3.24 mg/kg, and the range as 0.023-30.0 mg/kg (8).

Toxicology: The poisonous character of mercury compounds and the occupational hazard to men working in the mercury mines of Spain were recognized in ancient times. Nevertheless, mercurous chloride (calomel) was long used as an internal medicine, and mercuric chloride as a disinfectant. It has long been reported that adults could safely drink water containing from 4 to 12 mg of mercury per day, provided it is not in certain metallo-organic combinations. The toxicity of methylated mercury compounds is environmentally important. They accumulate in the food chains, and cause irreversible damage to nerve and brain cells. It is known that inorganic mercury can be methylated by bacteria, and that damage to wildlife has resulted in this way.

When using the very sensitive analytical methods now available, traces of mercury are found everywhere. Evidently, plants and animals can tolerate the small amounts occurring in nature.

Bioassay tests have indicated that fish may be harmed by mercury at concentrations as low as 0.01 mg/l, and possibly even lower. McKee & Wolf report partial inactivation of photosynthesis in giant kelp by concentrations of 0.05 mg/l (3).

Radioactive Properties: None

MOLYBDENUM (Mo)

Metallic molybdenum is grey in color with a melting point of 2610 C. It is chiefly valued for this latter property and its natural resistance to corrosion. Molybdenum forms six series of salts corresponding to the valency numbers of 0, $_{+}^{2}$, $_{+}^{3}$, $_{+}^{4}$, $_{+}^{5}$, or $_{+}^{6}$. Consequently, the chemistry of molybdenum is complex.

Occurrence: Molybdenum occurs only in small concentrations in the earth's crust (average 1.0 mg/kg). Mero reports levels of 0.01 mg/l in seawater (5).

There are no drinking water standards presently in force for molybdenum.

Yen reports a median concentration in crude oil of 0.031 mg/kg, and a range of 0.008-0.053 mg/kg (8).

Toxicology: Generally, molybdenum presents a low toxicity hazard to animal life. At low concentrations (0.1 mg/l in irrigation water) it is reported as an essential nutrient for plants, but at levels of 5 mg/l it becomes toxic. Plants tend to concentrate molybdenum which can lead to toxic effects on ruminants grazing in molybdenum-rich areas. Mckee & Wolf report toxicity towards fish in a range of 7-370 mg/l, towards alga at 54 mg/l, but show that E. Coli and Daphnia tolerated concentrations of 1000 mg/l (3).

Radioactive Properties: None

NICKEL (Ni)

Nickel is a hard, ductile, malleable, and very tenacious silvery-white metal. Hydrochloric and sulfuric acids, both dilute and concentrated, attack it slowly. Dilute nitric acid dissolves it readily, but the concentrated acid induces passivity.

Only one stable series of salts, the nickelous salts, which may be regarded as derived from the green nicklous oxide NiO, is known.

Occurrence: Nickel occurs in the range of 2 to 80 mg/kg in the earth's crust (4). In the ocean it has been reported at levels of 0.002 mg/l (5) and

0.005 mg/l (4). Surface waters are reported to contain up to 0.01 mg/l (4).

In plants, a few tenths of a mg/kg appear to be common, with up to several mg/kg in the leafy parts.

Compared with other metals, nickel is relatively abundant in crude oil. Yen reports median levels of 166 mg/kg and a range of 49-345 mg/kg. (8)

Toxicology: Towards humans, nickel is not a cumulative poison, and it appears that substantial amounts can be ingested without harmful consequences. However, nickel compounds inhaled as sprays or dusts have caused serious damage to the lungs. Certain plants and aquatic life are reported to show toxic effects starting at concentrations of 0.5 or 1.0 mg/l.

The toxic dose for dogs is reported to be 10-20 mg/kg of body weight, and the desirable limit for fish is considered to be 1.0 mg/l (3).

Radioactive Properties: None

OIL

By common consent, the term oil is used to denote a large group of complex hydrocarbons, which occurs widely in nature. Predominantly, these hudrocarbons include both the aliphatic and aromatic series and many substituted compounds. Their nature and distribution is too large a subject for this appendix. This discussion is limited to a general appraisal of the kinds of toxicity that might occur. These compounds have other attributes which are also of concern, principally, explosiveness and flammability.

Toxicology: No one simple statement can be made for such a large group of compounds. Their carcinogenity has already been discussed (see benz-A-pyrene), and only typical examples will be given below.

In the environment the toxicity of "oil" is often manifested by its coating action. Thus, fish kills result if oil coats the gills. Water fowl are killed if oil coats their feathers and they lose the protection of the air layer trapped beneath.

Toxic effects of light hydrocarbons when ingested are typified by the effects of gasoline on humans. If swallowed, it produces an intense burning sensation in the mouth and esophagus, with vomiting and diarrhea.

Restlessness, uncoordination, and cyanosis may occur. Recovery takes place within a few hours unless the petroleum has been aspirated into the lungs, in which case death follows rapidly from haemorrhagic pneumonia. The usual fatal dose for adults is said to be about 500 ml.

Acute poisoning from the inhalation of high concentrations of the vapor causes headache, nausea, and giddiness, proceeding in severe cases to unconsciousness, muscular tremors, convulsions, dyspnoea, cyanosis, and death. Chronic poisoning from continuous exposure to lower concentrations causes dullness, pain in the limbs, and other disturbances of the nervous system. It is much less liable than benzene to give rise to changes in the haemopoietic system.

McKee and Wolf (3) have an extensive discussion on oil, from which the following is taken:

> Fish and Other Aquatic Life: Oily substances may possibly be harmful to fresh-water aquatic life in the following manners:
>
> (1) Free oil and emulsions may act on the epithelial surfaces of fish, i. e., they adhere to the gills and interfere with respiration. Within limits, however, fish have a defensive mechanism to combat such action. They can secrete a mucous film to wash away irritants. If the concentration of oil is too heavy, oil will accumulate on the gills and cause asphyxia.
>
> (2) Free oil and emulsions may coat and destroy algae and other plankton, thereby removing a source of fish food. The coated organisms may agglomerate with suspended solids and settle to the bottom of the stream.
>
> (3) Settleable oily substances may coat the bottom, destroy benthal organisms, and interfere with spawning areas.
>
> (4) Soluble and emulsified material, ingested by fish, taint the flavor of the flesh.
>
> (5) Organic materials may deoxygenate the waters sufficiently to kill fish.

(6) Heavy coatings of free oil on the surface may interfere with the natural processes of reaeration and photosynthesis. Very light coatings would not be detrimental in this respect because of the wave action and other turbulence.

(7) Water-soluble principles may exert a direct toxic action on fish or fishfood organisms. Such toxicity may be acute or chronic. Acute toxicity will produce death or debility in 96 hours or less. Chronic toxicity exerts a long-time effect, through an accumulative action or through subtle changes in the ecology. By its very nature, chronic toxicity is difficult to prove. The material presented below deals primarily with acute toxicity attributable to soluble principles.

Certain petroleum products appear to have no soluble poisonous substances, but when emulsified and agitated with water, such oils prove deadly to fish. Chipman and Galtsoff (11) report that crude oil in concentrations as weak as 0.4 ml per liter (i.e., about 0.3 mg/l) is extremely toxic to fresh-water fish. The lethal limit of gasoline for rainbow trout has been reported as 100 mg/l. After 15 minutes exposure at 50 mg/l, rainbow trout show irritation and after 60 minutes they are tired. The toxic threshold is about 40 mg/l.

PHENOL

Phenol is the precursor in a series of organic compounds characterized by the formula R-OH; where R is an aromatic radical of varying degrees of complexity. The simple phenols (R = C_6H_5, C_6H_5,CH_3, etc.) are more toxic than the complex condensed phenols which occur in nature as tannins and other vegetable substances.

Occurrence: As in the case with cyanide, phenol is a compound that is both produced and destroyed by natural processes. To a smaller extent it is also produced and destroyed by human activities. The amounts found in the environment are the result of balances between inputs and losses. It is a normal constituent of surface waters, usually in amounts of a few thousandths of a mg/l. The normal concentration in human urine is about 30 mg/l. The cresols, as methyl derivatives of phenol, also occurring in nature but in smaller amounts, have similar properties. They also react in part in the analytical test, which is accordingly called "phenols."

The USPHS standard for drinking water (0.001 mg/l) is based mainly upon the undesirable taste forming chloro-phenols which result when phenolic waters are chlorinated.

Toxicology: Phenol in drinking water is toxic to man or other terrestrial animals at concentrations of several hundred mg/l. The data regarding fish are somewhat conflicting. The threshold concentration for adverse effects on fish may be around 1 mg/l, but some observations indicated that it may be as low as 0.2 mg/l. Other aquatic animal, planktonic or benthic, appear to be less sensitive. The cresols are more toxic, and the chlorinated phenols still more so to the same species.

POLYNUCLEAR AROMATIC HYDROCARBONS

Occurrence: This group of compounds, composed of fused benzene rings, has been given several names, of which polynuclear aromatics (PNA) and polyaromatic hydrocarbons (PAH) appear to be the most common. PNA's occur widely in nature. Up to 0.1% has been reported for the total PNA in crude oil (12), and Graf and Winter (13) reported levels of 0.4 to 1.7 mg/l of benz-A-pyrene in crude oil. Grimmer and Hildebrandt (14) have reported a range of .001-0.044 mg/kg in vegetable oils. Telgner (15) reported levels of 0.0002-0.02 mg/kg in foods. PNA's have also been reported in industrial and municipal waste effluents, solid, ground and surface waters, sediments, and biota (16).

Toxicology: The carcinogenity of some PNA's was discovered after observing that individuals in specific occupations involving prolonged exposure to coal tar products tended to show an abnormally high incidence of skin cancer. Research established that benz-A-pyrene (occurring at the 1.5% level in coal tar) produced skin carcinoma in laboratory animals, and subsequently, many other PNA's were shown to have that property. For mice, as little as 0.25 mg of benz-A-pyrene has produced tumors when injected subcutaneously.

SELENIUM (Se)

Selenium occurs in many different allotropic forms. Thus, it has no one set of physical constants. Since it has several oxidation states, several series of salts occur. Dilute acids do not react well with selenium.

Occurrence: Selenium occurs most commonly in shales (0.6 mg/kg) and to a lesser extent in igneous and sedimentary rocks. Mero reports levels of 0.004 mg/l in seawater, but Bowen gives concentrations of 0.00009 mg/l. Probably the spread of data reflects some analytical difficulty. The most recent data (17) gives the following:

Rocks	0.008 - 1.48	mg/kg
Black Shales	1.0 - 7.0	mg/kg
Crude Oil	0.03 - 1.4	mg/kg
Coal	0.56 - 5.14	mg/kg
Surface Water	0.0001-0.0004	mg/l
Seawater	0.0001	mg/l
Vegetation	0.01 - 0.50	mg/kg
Meat & Fish	1.0 - 4.6	mg/kg

Both the USPHS and the California standard for drinking water is 0.01 mg/l.

Toxicology: Selenium is one of a group of elements which is both an essential nutrient and a poison. It is necessary for good health at a level of 0.04 - 0.1 mg/kg and toxic at levels as low as 4 mg/kg in the diet.

Stock and wildlife show similar reactions to selenium, and for cattle the lethal dose is about 1 mg/kg of body weight. McKee and Wolf report that sublethal doses of selenium cause pathological changes in fish (3).

Radioactive Properties: None

SILVER (Ag)

Silver is a white, malleable and ductile metal. It is insoluble in dilute hydrochloric and sulfuric acids, but dissolves readily in nitric acid (2:1) and in boiling concentrated sulfuric acid.

Occurrence: Silver occurs at levels of 0.1 mg/kg in the earth's crust. In the ocean it occurs at levels of 0.0003 mg/l and in fresh water at levels of 0.00013 mg/l (5). Silver is accumulated by plants and animals in concentrations up to several mg/kg.

The USPHS standard for drinking water is 0.05 mg/l.

Little is known of the occurrence of silver in crude oil. "Traces" are reported in certain Mexican crude (8).

Toxicology: Very small concentrations of silver ion are lethal to most bacteria. For this reason, silver has been used for water sterilization. Unfortunately, the ion soon loses its activity under most conditions due to the formation of insoluble compounds. Concentrations of a few hundredths of a mg/l are lethal to zooplankton and fish. Terrestrial animals can tolerate the ingestion of quite large amounts. For example, the toxic dose for humans is reported at a high ten grams. When small quantities of silver are regularly injected, it accumulated in the body, but in an inert form, the only objectionable effect is a grey coloration of the skin and eyes, a condition that has resulted from certain medicinal uses of silver.

Radioactive Properties: None

VANADIUM (V)

Vanadium is a ductile lustrous metal, with relatively low strength and hardness. It has the ability to form several series of salts, generically analogous to ortho, meta, pyro, and polyacids.

Occurrence: Vanadium occurs in shales and igneous rocks at levels of 140 mg/kg. Similar levels occur in crude oils, mainly as an organic metallic porphyrin complex. In seawater vanadium occurs in the range of 0.002-0.003 mg/l and in fresh-water at levels of 0.001 mg/l. It is present at 106 mg/kg in plants, 0.15 mg/kg in land animals, and up to 2 mg/kg in the tissues of marine animals.

There are presently no public health drinking water standards for vanadium.

Toxicology: Vanadium is highly toxic to humans if ingested as an aerosol or if injected intravenously. No evidence has been published to suggest that vanadium compounds are absorbed in the gastro-intestinal tract, and it appears to have no biological role in animal metabolism. There is some evidence that in small quantities, it simulates plant growth and that it resembled molybdenum in promoting growth and activation os azotobacter.

Radioactive Properties: There are two naturally occurring isotopes of vanadium (atomic weights 50 and 51). Vanadium 50 occurs at an abundance of 0.24% and decays by β radiation with a half-life of 6×10^{14} years. If isolated, V50 is an extremely hazardous material.

ZINC (Zn)

Zinc is a fairly malleable and bluish-white metal ductile at 110-115 C. The pure metal dissolves very slowly in acids and in alkalis, although the presence of impurities or contact with platinum or copper, produced by the addition of a few drops of the solutions of these metals, accelerates the reaction. This explains the solubility of commercial zinc. The latter dissolves readily in dilute hydrochloric and in dilute sulfuric acid, with the evolution of hydrogen. Solution takes place with very dilute nitric acid, but no gas is evolved; with increasing concentration of acid, nitrous oxide or nitric oxide is evolved, depending upon the concentration; concentrated nitric acid has very little action owing to the very slight solbulity of zinc nitrate. Sulfur dioxide is evolved with hot concentrated sulfuric acid. Zinc also dissolves in solutions of caustic alkalis with the evolution of hydrogen and the formation of zincates.

Occurrence: Zinc is reported in the range of 16-95 mg/kg in the earth's crust (18). It is relatively soluble in water, being reported at levels of 0.01 mg/l in the ocean (5) and at levels of 5 mg/l in surface streams (6). Zinc is an essential nutrient and is the most abundant of the metals reviewed in this project. The concentrations in vegetation vary widely, generally being higher in the seeds than in other parts, and often exceeding 50 mg/kg. It seems to be present quite consistently in meats in concentrations generally ranging from 20 to 80 mg/kg, but ranging above 1,000 mg/kg in some seafoods.

Both the USPHS and the California standard for drinking water is 5 mg/l.

Zinc occurs at median levels of 29.8 mg/kg in crude oil, and in a range of 3.6 - 85.8 mg/kg.

Toxicology: The normal daily zinc intake of humans is estimated to be about 10 milligrams. At sufficient concentrations in drinking water, probably above 30 mg/l, zinc may cause nausea. At concentrations of several hundred mg/l it serves as an emetic.

Fish are far more sensitive towards zinc than mammals because of interference with the action of the gills. Reports of bioassay tests vary widely, probably because of the effect of other constituents in the water. In waters of high alkalinity, the zinc is mostly converted to insoluble forms. Some fish have withstood 10 to 15 mg/l in hard water, but concentrations of a few hundredths have been reported to be fatal to sensitive species in soft water.

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APPENDIX B*

METHODS EMPLOYED IN THE ANALYTICAL PROGRAM

1. SAMPLE RECEIPT

Upon receipt, the samples were logged on a master control sheet according to the numbers and codes assigned by the field sampling teams. The samples were examined and their appearance and odor recorded.

2. PRELIMINARY SEPARATION

The samples were thoroughly mixed and appropriate portions withdrawn for analysis. After weighing, each sample was mixed with benzene, and then allowed to stand to enable the phases to separate. The liquid phases were separated and both portions filtered to obtain the water and benzene insoluble. All three fractions were finally measured or weighed and the data recorded. Subsequent analysis was as follows:

(a) Aqueous Fraction

If the sample contained a measurable aqueous fraction, the pH of the fraction was determined by the glass-electrode method (1).

If the sample size permitted, ammonia nitrogen was then determined by distillation followed by titration with standard acid (2). When the sample was too small to permit distillation, ammonia nitrogen was determined by nesslerization (3).

(b) Benzene Fraction

The benzene layers were separated, dried over anhydrous sodium sulfate, and cleaned up if necessary prior to analysis by gas-liquid chromatography (see section 3(d) on Benz-A-pyrene).

(c) Proximate Analysis

In order to report the percentages of the three important phases, the solid residual was weighed and the aqueous phase measured volumetrically. For the purpose of this study "oil" was defined as the benzene solubles, but it proved impractical to measure this quantity directly. Consequently, the Freon method of analysis for oil and grease was adopted (4).

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*References for Appendix B: p. 225

3. INDIVIDUAL DETERMINATIONS

(a) Phenolic Compounds

Representative samples of the original sample were weighed as in (2) above. If samples contained oily matter, benzene was added to aid solution. Phenolic compounds were extracted with portions of 1N NaOH. The caustic layers were combined, acidified with H_3PO_4 and distilled. Phenolic compounds were then determined in the distillates by the aminoantipyrene method (5).

(b) Cyanides

An aliquot of the original sample was weighed and transferred to the distillation apparatus, and the evolved hydorcyanic acid was absorbed in 1N NaOH (6). Depending upon the cyanide concentration, the determination was carried out either by the pyridine-pyrazalone method (low concentrations) or by the silver nitrate titration method (high concentrations) (7).

(c) Selenium

A representative portion of the original sample was digested with a mixture of nitric-sulfuric acids (8), and distilled as the tetrabromide. The selenium was then quantified as the piazselenol, using the diaminobenzidine method (9).

(d) Benz-A-pyrene

Benz-A-pyrene was determined on the benzene extract of the original sample. For the gas-liquid chromatography (10,11,12) the following instrumentation was used:

(1) G. C., Varian Model 1200, H_2 flame ionization detector. Column: 10' x 1/8" SS, 2% SE-30 on 80/100 mesh Chromosorb W.

(2) G. C., Jarrell-Ash Model 700, electron capture (H_3) detector.
Column: 4' x 1/4" SS, 0.75% SE-30 on Chromosorb W.

In the determination of benz-A-pyrene, the hydrogen flame ionization detector instrument was used primarily for identification purposes, the relative retention time of unknown peaks being compared to known benzene solutions of benz-A-pyrene. Quantification was accomplished with an electron capture (H^3_2 source) detector taking advantage of: (a) this detector's relative insensitivity to hydrocarbons, and (b) the electron affinity of benz-A-pyrene. Peaks identified as benz-A-pyrene were quantified by comparison of the area under the peak of the unknown to the area of a know standard benz-A-pyrene peak.

(e) Chlorinated Hydrocarbons

A modification of method to detect chlorinated hydrocarbons in pesticides (13).

4. TRACE ELEMENTS

(a) Digestion

Weighed portions of the original sample were digested with a mixture of sulfuric and nitric acids in an apparatus designed to prevent volatilization losses of trace elements during the decomposition of organic matter (14).

(1) Apparatus

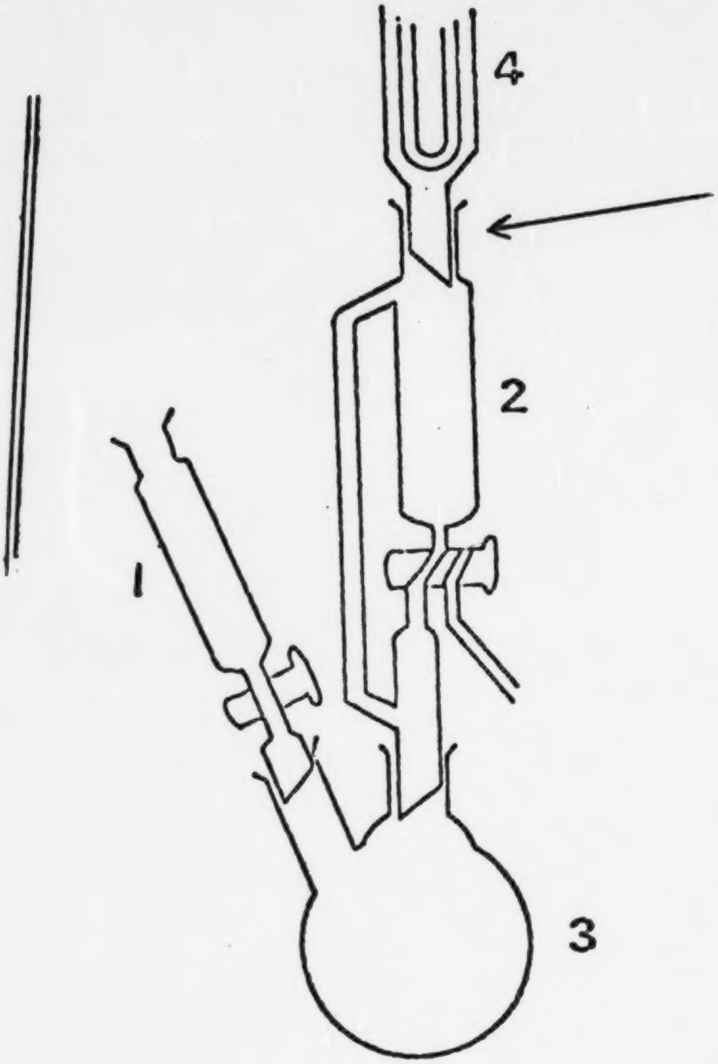
All glassware was cleaned with chromic acid followed by 1:1 nitric acid rinses. The digestion apparatus consisted of a 500-ml, 2-neck flask; a distillation receiver equipped with 2-way glass stopcock; an additional funnel; and a Friedrichs condenser (see Figure 1-B). All joints were lubricated with concentrated sulfuric acid.

(2) Procedure

To the weighed sample in the digestion flask, 25 ml of sulfuric and 50 ml of nitric acid were added. The mixture was refluxed until no more nitrous fumes were evolved. More nitric

FIGURE 1 - B

APPARATUS FOR THE WET OXIDATION OF OILS



All Joints
Ground Glass
(24/40)

1. 125 ml Additional Funnel
2. Distillation Receiver (SGA Scientific Inc., JF 8240)
3. 500 ml 2-neck Flask
4. Friedrichs Consenser

acid was added, as required, to maintain oxidizing conditions. The mixture was then evaporated until sulfuric acid fumes appeared, and was allowed to fume for five minutes, the distillate being collected in the receiver. The mixture was then allowed to cool. When cool, 25 ml of nitric acid were added dropwise and the digestate was again allowed to fume sulfuric acid for five minutes.

Upon cooling, the distillate was returned to the flask and the mixture was refluxed for 15 minutes. The flask contents were again distilled, the distillate being collected in the receiver. Upon cooling, the distillate was returned to the flask, the mixture was refluxed briefly, then allowed to cool. The condenser and receiver were rinsed with D. I. water.

The digested mixture was filtered through glass (GFC) paper. The flask was rinsed with de-ionized water, followed by three portions of ammonium-acetate solution (to dissolve water insoluble metallic sulfates, if present). The filtrate and washings were combined and made up to volume.

(b) Determination

(1) Arsenic

An aliquot of the filtrate from 4(a)(2) was fumed to SO_3 fumes to remove nitric acid. Arsenic was determined by the arsine generation method, the arsine being reacted with silver diethyldithiocarbamate. The red complex was read on a photometer at 535 mu (15).

(2) Mercury

Mercury was determined on an aliquot from procedure 4(a)(2) (above) by the cold-vapor (flameless) atomic absorption method (16). (Digestion: modification of 4(a) above.)

(3) Trace Metals

Beryllium, vanadium, chromium, cobalt, nickel, copper, zinc, silver, cadmium, lead, and molybdenum were determined on the filtered digestate by atomic absorption spectrophotometry.

In most cases, the filtrate could be aspirated directly; dilutions were made when the concentration exceeded the linear working range. Although standards were made up to approximate the sample matrix, the use of Deuterium background correction was required for some elements (17, 18, 19).

(4) Blanks and Spiked Samples

Blanks and actual samples spiked with known amounts of the trace elements to be determined were routinely carried through the extraction and digestion procedures. Recoveries are tabluated in the main body of the analytical report

References (Appendix B):

1. Standard methods for the examination of water and wastewater. 13th ed. New York, American Public Health Association Publication Office, 1971. Section 144A, p. 276-280.

2. Ibid Section 132A, p. 224-226.

3. Ibid Section 132B, p. 226-231.

4. Methods for chemical analysis of water and wastes. Environmental Protection Agency Publication 625/6-74-003. U. S. Government Printing Office, 1974. p.226.

5. Standard methods for the examination of water and wastewater. 13th ed. New York, American Public Health Association Publication Office, 1971. Section 222B, p. 502-503.

6. Ibid Section 207A, p. 399-402.

7. Ibid Section 207B and 207C, p. 402-406.

8. Methods of analysis of the Association of Official Analytical Chemists (AOAC). 11th ed. Washington, D. C., AOAC Publications, 1970. Method 3.073, p. 46-48.

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11. Dawson, Jr., H. J. Detection of traces of polynuclear aromatics in hydrocarbons by gas chromatography. Ibid 36(9): 1852-1853, Aug. 1964.

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18. Operating manual for Model 303 atomic absorption spectrophotometer. The Perkin-Elmer Corporation, Norwalk, Connecticut, Jan. 1969.

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APPENDIX C

ANALYTICAL QUALITY CONTROL DATA FOR QUANTIFICATION OF LABORATORY ERROR

Refinery waste samples were analyzed to determine their concentration levels of various identified hazardous constituents. After the addition of known quantities of these substances to the samples, concentration levels were measured again. Comparison of the results made possible the evaluation of laboratory accuracy. (Discussion of control methodology and data significance appears in Section 3. 4 of this report.)

APPENDIX C

ANALYTICAL QUALITY CONTROL DATA FOR QUANTIFICATION OF LABORATORY ERROR

Arsenic (As)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	23.5	2.3	25.8	26.4	+0.6
A-4	Slop oil emulsion solids	3.5	2.5	6.0	6.0	0.0
A-5	Spent lime	0.05	0.5	0.55	0.74	+0.19
C2-8	Soil farm compos.	8.2	0.0	8.2	8.2	0.0
C4-6	Sulfonation waste	<0.5	5.0	5.5	4.4	-1.1
C4-3	Centrifuge cake	2.5	4.6	7.1	11.7	+4.6
B2-1	API separator sludge	5.4	5.0	10.4	10.8	+0.4
B4-7	Lube oil clarif. bottoms	3.8	5.0	8.8	7.8	-1.0
	Lube oil clarif. bottoms	3.8	5.0	8.8	10.0	+1.2
B5-5	Waste bio sludge	2.0	0.0	2.0	2.0	0.0
C1-7	Spent lime	1.0	5.0	6.0	8.2	+2.2
C3-1	Kerosene filter clay	1.4	0.0	1.4	2.0	+0.6
A4-3	Slop oil emulsion solids	7.8	5.0	12.8	13.2	+0.4
C2-2	DAF float	<0.5	5.0	5.5	8.5	+3.0
A2-9	Vacuum filter cake	47.5	0.0	47.5	45.5	-2.0
B2-2	Leaded tank bottoms	525.0	0.0	525.0	455.0	-70.0

*0.0 in this column indicates a duplicate analysis

Beryllium (Be)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	0.50	2.3	2.8	2.3	-0.5
A-4	Slop oil emulsion solids	0.38	2.4	2.78	2.4	-0.38
A-5	Spent lime	<0.1	0.5	0.6	0.3	-0.3
A3-3	API separator sludge	0.24	4.9	5.14	5.2	+0.06
C2-8	Soil farm compos.	1.9	0.0	1.9	1.9	0.0
C4-6	Sulfonation waste	<0.12	5.0	5.12	5.3	+0.18
C4-3	Centrifuge cake	0.22	4.6	4.82	4.9	+0.08
B2-1	API separator sludge	<0.25	5.0	5.25	5.0	-0.25
B4-7	Lube oil clarif. bottoms	<0.13	5.0	5.13	4.3	-0.83
	Lube oil clarif. bottoms	<0.13	5.0	5.13	4.3	-0.83
B5-5	Waste bio sludge	<0.13	0.0	<0.13	<0.13	0.0
C1-7	Spent lime	<0.13	5.0	5.13	4.5	-0.63
C3-1	Kerosene filter clay	0.50	0.0	0.50	<0.25	-0.25
A4-3	Slop oil emulsion solids	<0.25	5.0	5.25	4.3	-0.95
B4-11	Kerosene filter clay	<0.25	0.0	<0.25	<0.25	0.0
C2-2	DAF float	<0.25	5.0	5.25	4.3	-0.95

*0.0 in this column indicates a duplicate analysis

Cadmium (Cd)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	0.12	4.5	4.62	1.9	-2.72
A-4	Slop oil emulsion solids	0.30	4.9	5.2	4.7	-0.5
A-5	Spent lime	0.03	1.0	1.03	0.39	-0.64
A3-3	API separator sludges	<0.24	9.8	10.04	3.4	-6.64
C2-8	Soil farm compos.	2.0	0.0	2.0	1.3	-0.7
C4-6	Sulfonation waste	<0.1	10.0	10.1	1.0	-9.1
C4-3	Centrifuge cake	0.5	9.2	9.7	4.6	-5.1
B2-1	API separator sludge	0.5	10.0	10.5	9.0	-1.5
B4-7	Lube oil clarif. bottoms	0.3	10.0	10.3	10.0	-0.3
	Lube oil clarif. bottoms	0.3	10.0	10.3	10.0	-0.3
B5-5	Waste bio sludge	0.3	0.0	0.3	0.3	0.0
C1-7	Spent lime	0.3	10.0	10.3	10.0	-0.3
C3-1	Kerosene filter clay	1.5	0.0	1.5	1.5	0.0
A4-3	Slop oil emulsion solids	<0.25	10.0	10.25	7.0	-3.25
B4-11	Spent clay	<0.25	0.0	<0.25	<0.25	0.0
C2-2	DAF float	<0.25	10.0	10.25	7.0	-3.25
C4-4	Spent lime	0.1	0.0	0.1	0.25	+0.15

*0.0 in this column indicates a duplicate analysis

Chromium (Cr)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	850.0	9.1	859.1	625.0	-234.1
A-4	Slop oil emulsion solids	444.0	9.8	453.8	478.0	+24.2
A-5	Spent lime	0.07	2.0	2.07	1.2	-0.87
A3-3	API separator sludge	6790.0	20.0	6810.0	6860.0	+50.0
C2-8	Soil farm compos.	288.0	0.0	288.0	338.0	+50.0
C4-6	Sulfonation waste	0.2	20.2	20.2	16.5	-3.7
C4-3	Centrifuge cake	536.0	18.0	554.0	551.0	-3.0
B2-1	API separator sludge	445.0	20.0	465.0	405.0	-60.0
B4-7	Lube oil clarif. bottoms	40.0	20.0	60.0	48.0	-12.0
	Lube oil clarif. bottoms	40.0	20.0	60.0	55.0	-5.0
B5-5	Waste bio sludge	475.0	0.0	475.0	475.0	0.0
C1-7	Spent lime	0.5	20.0	20.5	14.3	-6.2
C3-1	Kerosene filter clay	45.0	0.0	45.0	45.0	0.0
A4-3	Slop oil emulsion solids	380.0	20.0	400.0	393.0	-7.0
B4-11	Kerosene filter clay	1.3	0.0	1.3	1.3	0.0
C2-2	DAF float	28.0	20.0	48.0	42.0	-6.0
B2-5	DE filter cake	1750.0	0.0	1750.0	2100.0	+350.0
C2-5	Centrifuge cake	1175.0	0.0	1175.0	1250.0	+75.0
C4-2	DAF float	117.5	0.0	117.5	123.0	+5.5
C4-4	Spent lime	28.0	0.0	28.0	29.5	+1.5
C3-3	API separator sludge	285.0	0.0	285.0	220.0	-65.0
C3-5	Cooling tower sludge	343.0	0.0	343.0	376.0	+33.0

*0.0 in this column indicates a duplicate analysis

Copper (Cu)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	27.5	9.1	36.6	141.0	+104.4
A-4	Slop oil emulsion solids	15.9	9.8	25.7	27.0	+1.3
A-5	Spent lime	0.22	2.0	2.22	1.7	-0.52
A3-3	API separator solids	514.0	20.0	534.0	515.0	-19.0
C2-8	Soil farm compos.	112.0	0.0	112.0	112.0	0.0
C4-6	Sulfonation waste	6.3	20.0	26.3	17.0	-9.3
C4-3	Centrifuge cake	111.0	18.0	129.0	124.0	-5.0
B2-1	API separator sludge	29.0	20.0	49.0	46.5	-2.5
B4-7	Lube oil clarif. bottoms	3.0	20.0	23.0	17.5	-5.5
	Lube oil clarif. bottoms	3.0	20.0	23.0	17.5	-5.5
B5-5	Waste bio sludge	9.5	0.0	9.5	9.5	0.0
C1-7	Spent lime	2.0	20.0	22.0	18.5	-3.5
C3-1	Kerosene filter clay	8.0	0.0	8.0	7.5	-0.5
A4-3	Slop oil emulsion solids	31.5	20.0	51.5	47.8	-3.7
B4-11	Kerosene filter clay	0.5	0.0	0.5	0.5	0.0
C2-2	DAF float	0.5	20.0	20.5	15.5	-5.0
A3-3	API separator sludge	514.0	0.0	514.0	500.0	-14.0
A2-6	Kerosene filter clay	9875.0	0.0	9875.0	14780.0	+4905.0

*0.0 in this column indicates a duplicate analysis

Cobalt (Co)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	25.0	9.1	34.1	50.0	+15.9
A-4	Slop oil emulsion solids	4.2	9.8	14.0	14.0	0.0
A-5	Spent lime	0.18	2.0	2.18	1.7	-0.48
A3-3	API separator sludge	26.2	20.0	46.2	42.2	-4.0
C2-8	Soil farm compos.	14.0	0.0	14.0	17.5	+3.5
C4-6	Sulfonation waste	<0.2	20.0	20.2	24.0	+3.8
C4-3	Centrifuge cake	74.0	18.0	92.0	87.0	-5.0
B2-1	API separator sludge	<1.0	20.0	21.0	15.5	-5.5
B4-7	Lube oil clarif. bottoms	<0.5	20.0	20.5	16.3	-4.2
	Lube oil clarif. bottoms	<0.5	20.0	20.5	16.3	-4.2
B5-5	Waste bio sludge	0.5	0.0	0.5	0.5	0.0
C1-7	Spent lime	<0.5	20.0	20.5	17.3	-3.2
C3-1	Kerosene filter clay	5.0	0.0	5.0	5.0	0.0
A4-3	Slop oil emulsion solids	5.0	20.0	25.0	15.0	-10.0
C2-2	DAF float	2.0	20.0	22.0	15.0	-7.0
C4-2	DAF float	67.5	0.0	67.5	10.3	-57.2

*0.0 in this column indicates a duplicate analysis

Cyanide

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
C4-9B	Leaded tank bottoms	<0.08	1.17	1.25	1.46	+0.21
C4-6	Sulfonation waste	<0.08	200.0	200.08	141.0	-59.08
B5-5	Waste bio sludge	<0.10	0.80	0.90	1.05	+0.15
B4-7	Lube oil clarif. bottoms	<0.10	0.80	0.90	0.83	-0.07
A4-3	Slop oil emulsion solids	0.40	1.00	1.40	1.62	+0.22
C2-2	DAF float	<0.1	1.00	1.10	0.77	-0.33
A3-3	API separator sludge	51.4	0.0	51.4	36.2	-15.2
C4-10	Loading tank sludge	17.2	0.0	17.2	10.8	-6.4
A1-1	Sludge facult pond	19.5	0.0	19.5	19.0	-0.5
A1-2	Centrifuge cake	54.4	0.0	54.4	50.5	-3.9
C4-11	Storm water silt	0.34	0.0	0.34	0.61	+0.27

*0.0 in this column indicates a duplicate analysis

Lead (Pb)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	12.0	9.1	21.1	91.0	+69.9
A-5	Spent lime	<0.1	2.0	2.1	0.1	-2.0
A3-3	API separator sludge	60.6	19.6	80.2	61.3	-18.9
C2-8	Soil farm compos.	1100.0	0.0	1100.0	750.0	-350.0
C4-6	Sulfonation waste	9.5	20.0	29.5	27.5	-2.0
C4-3	Centrifuge cake	28.1	18.3	46.4	51.5	+5.1
B2-1	API separator sludge	10.0	20.0	30.0	50.0	+20.0
B4-7	Lube oil clarif. bottoms	1.3	20.0	21.3	18.8	-2.5
	Lube oil clarif. bottoms	1.3	20.0	21.3	18.5	-2.8
B5-5	Waste bio sludge	5.0	0.0	5.0	5.0	0.0
C1-7	Spent lime	2.5	20.0	22.5	13.8	-8.7
C3-1	Kerosene filter clay	<2.5	0.0	<2.5	<2.5	0.0
A4-3	Slop oil emulsion solids	10.8	20.0	30.8	7.8	-23.0
B4-11	Kerosene filter clay	2.3	0.0	2.3	2.3	0.0
A3-7	FCC catalyst fines	195.0	0.0	195.0	355.0	+160.0
A3-8	Combined lime & FCC sludge	198.0	0.0	198.0	145.0	-53.0
B2-5	DE filter cake	275.0	0.0	275.0	39.0	-236.0
B4-1	Flotator	1250.0	0.0	1250.0	1390.0	+140.0
B4-2	Tank bottom	388.0	0.0	388.0	258.0	-130.0
B4-4	API separator sludge	1290.0	0.0	1290.0	69.0	-1221.0
C4-4	Spent lime	6.8	0.0	6.8	2.3	-4.5
C4-5	FCC catalyst fines	94.8	0.0	94.8	68.0	-26.8
C4-9B	Leaded tank bottoms	1420.0	0.0	1420.0	780.0	-640.0
C3-2	FCC catalyst fines	59.0	0.0	59.0	39.0	-20.0
B1-3	Aerated pond sludge	1.2	0.0	1.2	4.4	+3.2

*0.0 in this column indicates a duplicate analysis

Mercury (Hg)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A3-3	API separator sludge	0.32	0.29	0.61	0.50	-0.11
C2-8	Soil farm compos.	2.00	0.0	2.00	1.82	-0.18
C4-6	Sulfonation waste	0.07	0.3	0.37	0.22	-0.15
B2-1	API separator sludge	0.05	0.30	0.35	0.65	+0.30
B4-7	Lube oil clarif. bottoms	0.10	0.30	0.40	0.37	-0.03
B5-5	Waste bio sludge	1.28	0.0	1.28	1.08	-0.20
C1-7	Spent lime	<0.04	0.30	0.34	0.32	-0.02
A-4	Slop oil emulsion solids	0.88	0.15	1.03	1.34	+0.31
A-5	Spent lime	<0.01	0.03	0.04	<0.01	-0.03
A-1	Centrifuge cake	2.50	0.14	2.64	5.23	+2.59
C2-2	DAF float	0.07	0.30	0.37	0.38	+0.01
B4-11	Kerosene filter clay	<0.04	0.0	<0.04	<0.04	0.0
A-8	Bundle cleaner sump	20.0	0.0	20.0	23.3	+3.3
B5-3	API separator sludge	6.2	0.0	6.2	7.9	+1.7
C3-5	Cooling tower sump	3.35	0.0	3.35	0.09	-3.26
C4-4	Spent lime	2.73	0.0	2.73	<0.04	-2.69

*0.0 in this column indicates a duplicate analysis

Molybdenum (Mo)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	30.0	22.7	52.7	59.0	+6.3
A-4	Slop oil emulsion solids	3.8	25.0	28.8	18.8	-10.0
A-5	Spent lime	<0.25	5.0	5.25	6.0	+0.75
A3-3	API separator sludge	19.4	49.0	68.4	122.0	+53.6
C2-8	Soil farm compos.	<5.0	0.0	<5.0	<5.0	0.0
C4-6	Sulfonation waste	<5.0	50.0	55.0	70.0	+15.0
C4-3	Centrifuge cake	10.0	46.0	56.0	103.0	+47.0
B2-1	API separator sludge	5.0	50.0	55.0	85.0	+30.0
B4-7	Lube oil clarif. bottoms	<2.5	50.0	52.5	50.0	-2.5
	Lube oil clarif. bottoms	<2.5	50.0	52.5	50.0	-2.5
B5-5	Waste bio sludge	<2.5	0.0	<2.5	<2.5	0.0
C-17	Spent lime	<2.5	50.0	52.5	75.0	+22.5
C3-1	Kerosene filter clay	<5.0	0.0	<5.0	<5.0	0.0
A4-3	Slop oil emulsion solids	<2.5	50.0	52.5	108.0	+55.5
B4-11	Spent clay	<2.5	0.0	2.5	2.5	0.0
C2-2	DAF float	<2.5	50.0	52.5	103.0	+50.5
A-8	Bundle cleaning sump	463.0	0.0	463.0	850.0	+387.0

*0.0 in this column indicates a duplicate analysis

Nickel (Ni)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	288.0	50.0	338.0	341.0	+3.0
A-4	Slop oil emulsion solids	35.0	49.0	84.0	368.0	+284.0
A-5	Spent lime	1.0	10.0	11.0	6.8	-4.2
A3-3	API separator sludge	150.0	98.0	248.0	250.0	+2.0
C2-8	Soil farm compos.	60.0	0.0	60.0	65.0	+5.0
C4-6	Sulfonation waste	15.0	100.0	115.0	92.5	-22.5
C4-3	Centrifuge cake	129.0	97.0	226.0	216.0	-10.0
B2-1	API separator sludge	7.5	100.0	107.5	97.5	-10.0
B4-7	Lube oil clarif. bottoms	<2.5	100.0	102.5	93.0	-9.5
	Lube oil clarif. bottoms	<2.5	100.0	102.5	100.0	-2.5
B5-5	Waste bio sludge	2.5	0.0	2.5	2.5	0.0
C1-7	Spent lime	1.3	100.0	101.3	113.0	+11.7
C3-1	Kerosene filter clay	22.0	0.0	22.0	16.0	-6.0
A4-3	Slop oil emulsion solids	60.0	100.0	160.0	138.0	-22.0
B4-11	Kerosene filter clay	2.5	0.0	2.5	2.5	0.0
C2-2	DAF float	<2.5	100.0	102.5	82.5	-20.0
A4-7	Vacuum filter cake	1100.0	0.0	1100.0	950.0	+150.0
C1-2	FCC catalyst fines	1000.0	0.0	1100.0	925.0	-75.0
C4-4	Spent lime	19.4	0.0	19.4	20.0	+0.6
B1-3	Aerated pond sludge	<2.5	0.0	<2.5	17.1	+14.6
B1-5	FCC catalyst fines	586.0	0.0	586.0	411.0	-175.0

*0.0 in this column indicates a duplicate analysis

Phenolic Compounds

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
B2-1	API separator sludge	6.5	48.5	55.0	50.0	-5.0
B4-7	Lube oil clarif. bottoms	2.1	48.5	50.6	45.0	-5.6
B5-5	Waste bio sludge	4.5	48.5	53.0	47.6	-5.4
C1-7	Spent lime	2.3	48.5	50.8	50.5	-0.3
C3-1	Kerosene filter clay	6.4	48.5	54.9	40.8	-14.1
A3-8	Lime & FCC fine slidges	4.4	85.0	89.4	86.0	-3.4
A2-16	Soil farm comp.	7.9	85.0	92.9	56.0	-36.9
C4-8	Tergol filter clay	2.0	85.0	87.0	60.0	-27.0
A4-3	Slop oil emulsion solids	33.6	47.4	81.0	74.2	-6.8
B2-9	Coke fines	2.5	0.0	2.5	1.5	-1.0
B4-11	Spent clay	<0.5	0.0	<0.5	<0.5	0.0
B1-4	Cooling tower sludge	4.1	10.6	14.7	14.5	-0.2
A1-10	Crude tank bottoms	21.0	10.3	31.3	22.0	-9.3
B1-1	Holding basin	32.0	10.6	42.6	24.0	-18.6
A1-10	Crude tank bottoms	21.0	0.0	21.0	10.2	-10.8
A-2	API separator sludge	157.0	0.0	157.0	72.4	-84.6
A3-2	Neutralized HF alkylation sludge	14.6	0.0	14.6	16.2	+1.6
A2-14	Crude tank bottoms	15.0	0.0	15.0	11.6	-3.4
A3-7	FCC catalyst fines	72.0	0.0	72.0	10.5	-61.5
B4-2	Crude tank bottoms	16.5	0.0	16.5	37.8	+21.3

*0.0 in this column indicates a duplicate analysis

Phenolic Compounds (continued)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
B5-4	Slop oil emulsion solids	68.0	0.0	68.0	78.5	+10.5
B1-1	Holding basin	32.0	0.0	32.0	8.9	-23.1
B1-3	Aerated holding pond	10.3	0.0	10.3	6.2	-4.1
B1-4	Cooling tower sludge	4.1	0.0	4.1	3.6	-0.5
C4-9A	Nonleaded tank bottoms	1.7	0.0	1.7	1.5	-0.2

*0.0 in this column indicates a duplicate analysis

Selenium (Se)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A4-3	Slop oil emulsion solids	<1.0	10.0	11.0	9.6	-1.4
C2-2	DAF float	2.0	10.0	12.0	4.1	-7.9
B5-5	Waste bio sludge	<1.0	10.0	11.0	9.2	-1.8
C3-1	Kerosene filter clay	2.1	10.0	12.1	10.1	-2.0
C1-7	Spent lime	<1.0	10.0	11.0	<1.0	-10.0
A-9	Sulfur spill clean-up	<2.0	10.0	12.0	9.2	-2.8
C4-3	Centrifuge cake	8.8	0.0	8.8	6.7	-2.1
	Centrifuge cake	8.8	0.0	8.8	5.8	-3.0
B1-1	Holding basin	7.6	0.0	7.6	2.3	-5.3

*0.0 in this column indicates a duplicate analysis

Silver (Ag)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centfifuge cake	0.8	4.5	5.3	2.5	-2.8
A-4	Slop oil emulsion solids	0.2	4.9	5.1	4.1	-1.0
A-5	Spent lime	0.05	0.95	1.0	1.05	+0.05
C2-8	Soil farm compos.	0.5	0.0	0.5	0.5	0.0
C4-6	Sulfonation waste	0.25	10.0	10.25	8.9	-1.35
C4-3	Centrifuge cake	20.1	9.2	29.3	27.5	-1.8
B2-1	API separator sludge	0.5	10.0	10.5	10.0	-0.5
B4-7	Lube oil clarif. bottoms	0.3	10.0	10.3	8.0	-2.3
	Lube oil clarif. bottoms	0.3	10.0	10.3	3.8	-6.5
B5-5	Waste bio sludge	0.5	0.0	0.5	0.5	0.0
C1-7	Spent lime	0.5	10.0	10.5	5.3	-5.2
C3-1	Kerosene filter clay	1.0	0.0	1.0	1.0	0.0
A4-3	Slop oil emulsion solids	<0.13	10.0	10.13	7.5	-2.63
B4-11	Kerosene filter clay	<0.13	0.0	<0.13	<0.13	0.0
C2-2	DAF float	0.50	10.0	10.5	5.0	-5.5
C4-3	Centrifuge cake	20.1	0.0	20.1	17.0	-3.1

*0.0 in this column indicates a duplicate analysis

Vanadium (V)

No.	Sample	Found in Original Sample mg/kg	Amount of Spike* mg/kg	Calculated Spiked Sample Concen. mg/kg	Found in Spiked Sample mg/kg	Error mg/kg
A-1	Centrifuge cake	66.0	45.0	111.0	116.0	+5.0
A-4	Slop oil emulsion solids	11.0	49.0	60.0	64.0	+4.0
A-5	Spent lime	<0.7	10.0	10.7	<10.0	-0.7
A3-3	API separator sludge	48.5	98.0	146.5	167.0	+20.5
C2-8	Soil farm compos	90.0	0.0	90.0	85.0	-5.0
C4-6	Sulfonation waste	7.5	100.0	107.5	115.0	+7.5
C4-3	Centrifuge cake	75.0	92.0	167.0	161.0	-6.0
B2-1	API separator sludge	15.0	100.0	115.0	125.0	+10.0
B4-7	Lube oil clarif. bottoms	<5.0	100.0	105.0	90.0	-15.0
	Lube oil clarif. bottoms	<5.0	100.0	105.0	90.0	-15.0
B5-5	Waste bio sludge	5.0	0.0	5.0	<5.0	0.0
C1-7	Spent lime	<5.0	100.0	105.0	103.0	+2.0
C3-1	Kerosene filter clay	65.0	0.0	65.0	70.0	+5.0
A4-3	Slop oil emulsion solids	5.0	100.0	105.0	115.0	+10.0
B4-11	Kerosene filter clay	<5.0	0.0	<5.0	<5.0	0.0
C2-2	DAF float	<5.0	100.0	105.0	110.0	+5.0
A1-4	Soil (control)	115.0	0.0	115.0	115.0	0.0
A4-9	FCC catalyst fines	82.5	0.0	82.5	70.0	-12.5
C4-2	DAF float	15.0	0.0	15.0	10.0	-5.0
C4-4	Spent lime	31.6	0.0	31.6	25.0	-6.6
C4-10	Crude tank bottoms	35.0	0.0	35.0	48.8	+13.8

*0.0 in this column indicates a duplicate analysis

APPENDIX D

COMPARISON OF INTER-LABORATORY ANALYTICAL DATA

To evaluate analytical quality control, samples collected at the various refineries were split into identical pairs. One sample was left at the refinery for analysis within their laboratories. The results of analyses of five participating refineries are shown here with those of identical samples analyzed in the laboratories of Jacobs Engineering Co.

APPENDIX D

COMPARISON OF INTER-LABORATORY ANALYTICAL DATA JACOBS ENGINEERING (JE) WITH REFINERIES

(All Numbers in mg/kg Except Where Noted)

SAMPLE TYPE	API Separator Sludge		Neutralized HF Alkylation Sludge		FCC Catalyst Fines		Spent Lime From Boil Feedwater Treatment		API Separator Sludge		API Separator Sludge		No 2 Holding Pond Sludge	
REFINERY CODE	A-3		A-3		A-3		A-3		B-1		B-1		B-1	
	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery
COMPONENT														
Phenols	9.1	6.0	15.4	28.08	10.5	12.6	1.8	0.7	32.0	0.04	19.4	3.06	10.2	0.30
Cyanide	43.6	35.5	0.21	0.05	----	0.65	<0.004	2.05	0.15	0.27	6.9	1.1	5.8	2.6
Selenium (Se)	4.3	0.36	1.0	<0.03	1.1	<0.03	<1.0	0.23	7.6	<2.0	<2.0	<2.0	5.4	<2.0
Arsenic (As)	32.0	80.0	<0.5	45.65	<0.5	0.7	<0.5	1.0	9.4	6.9	14.4	8.9	1.6	1.7
Mercury (Hg)	0.32	103.0	0.09	2.5	0.16	<2.0	<0.04	<2.0	0.15	<0.05	1.12	1.8	[illegible]	<0.05
Beryllium (Be)	0.24	<0.1	0.13	0.14	1.25	0.38	<0.12	0.23	<0.2	<1.0	<0.2	<1.0	<[illegible]	<1.0
Vanadium (V)	48.5	<10.0	<2.5	<10.0	240.0	<10.0	<2.5	<10.0	28.0	15.0	4.0	<5.0	<1.2	<5.0
Chromium (Cr)	6790.0	2.59	5.0	5.91	82.5	4.31	5.3	7.34	750.0	300.0	279.0	200.0	331.0	275.0
Cobalt (Co)	26.2	5.66	0.7	39.7	4.0	2.01	1.0	4.0	1.0	5.0	2.8	15.0	0.2	5.0
Nickel (Ni)	150.4	15.1	7.4	5.52	117.5	23.9	26.2	17.2	13.8	25.0	12.5	60.0	<2.5	30.0
Copper (Cu)	507.0	0.61	2.5	1.16	17.3	3.30	3.8	3.29	77.0	60.0	93.0	120.0	10.2	8.0
Zinc (Zn)	6596.0	342.0	8.6	9.21	77.5	12.9	27.5	20.7	388.0	310.0	150.0	300.0	122.0	80.0
Silver (Ag)	0.97	0.75	0.12	0.87	2.1	0.43	0.25	0.81	0.2	<2.0	0.1	<2.0	0.1	<2.0
Cadmium (Cd)	<0.24	0.17	<0.12	0.34	<0.12	0.34	<0.12	0.86	0.29	2.0	0.54	7.0	0.16	1.0
Lead (Pb)	60.6	7.17	9.6	6.64	274.0	7.76	7.3	10.[illegible]	5.0	11.0	13.8	40.0	1.2	9.0
Molybdenum (Mo)	19.4	----	<2.5	----	6.3	----	<2.5	----	3.8	<5.0	14.0	<5.0	2.5	<5.0
Ammonium Salts (as NH_4)	----	----	<0.2	----	----	----	4.0	----	3.0	----	3.5	----	6.5	----
Benz-A-Pyrene (PNA)	3.7	16.2	<0.2	82.1	1.5	2.2	<0.2	81.1	<0.3	----	<0.3	----	<0.3	----
Oil and Grease (Benzene Ext.)	14.5%	8.5%	7.1%	153	0.05%	1049	0.25%	136	12.7%	0.9%	23.0%	6.3%	0.5%	0.9%

(All numbers in mg/kg except where noted)

SAMPLE TYPE	Cooling Tower Sludge		FCC Catalyst Fines		API Separator Sludge		Coker Blowdown Pond Coke Fines		Slop Oil Emulsion Solids		Boiler House Solids		Waste Bio Sludge	
REFINERY CODE	B-1		B-1		B-5		B-5		B-5		B-5		B-5	
	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery
COMPONENT														
Phenols	3.8	0.10	1.4	---	112.0	55.0	75.0	90.0	73.0	50.0	3.6	1.1	4.5	1.1
Cyanide	<0.03	0.08	0.16	---	<0.10	<0.2	<0.1	<0.2	<0.10	<0.2	<0.10	<0.2	<0.10	<0.2
Selenium (Se)	<2.0	<2.0	<2.0	<2.0	1.0	<1.0	1.9	2.0	1.6	<1.0	<1.0	<1.0	<1.0	<1.0
Arsenic (As)	0.7	0.2	2.4	2.0	7.0	3.0	1.4	<1.0	8.6	11.0	<1.0	<1.0	2.0	1.0
Mercury (Hg)	<0.04	<0.05	<0.04	<0.05	7.2	10.0	<0.04	<0.5	12.25	12.0	0.17	<0.5	1.28	2.0
Beryllium (Be)	0.1	<1.0	0.2	<1.0	<0.25	0.5	<0.25	0.5	<0.25	0.5	<0.13	0.1	<0.13	0.1
Vanadium (V)	<1.2	<5.0	940.0	1600.0	<10.0	19.0	<10.0	4.0	15.0	6.0	<5.0	7.0	5.0	1.0
Chromium (Cr)	181.0	60.0	41.0	110.0	280.0	400.0	<1.0	0.3	525.0	740.0	5.8	2.0	475.0	540.0
Cobalt (Co)	0.38	2.0	6.5	20.0	13.0	20.0	<1.0	<0.1	34.5	45.0	<0.5	<0.1	0.5	1.0
Nickel (Ni)	<2.5	8.0	586.0	50.0	10.0	10.0	<2.5	6.0	14.0	20.0	<1.3	<1.0	2.5	5.0
Copper (Cu)	13.0	5.0	4.1	<2.0	23.0	40.0	2.5	2.0	360.0	16.0	9.5	18.0	9.5	14.0
Zinc (Zn)	118.0	50.0	19.0	30.0	340.0	520.0	13.0	30.0	60.0	300.0	15.0	20.0	153.0	200.0
Silver (Ag)	<0.1	<1.1	1.2	<2.0	1.5	3.0	<0.5	<1.0	1.5	3.0	0.5	3.0	0.5	1.0
Cadmium (Cd)	0.06	<1.0	0.12	2.0	2.0	1.0	0.5	0.1	2.0	1.0	<0.3	0.2	0.3	0.2
Lead (Pb)	1.2	1.0	17.0	40.0	<2.5	19.0	<2.5	9.0	<2.5	5.0	3.8	8.0	5.0	12.0
Molybdenum (Mo)	1.2	<5.0	12.0	25.0	10.0	5.0	<5.0	1.5	5.0	2.0	<2.5	<1.0	<2.5	<1.0
Ammonium Salts (as NH_4)	2.5	---	---	14.0	---	---	---	---	8.0	---	<0.5	---	15.0	---
Benz-A-Pyrene (PNA)	<0.3	---	<0.3	---	1.8	---	---	---	<1.5	---	<0.2	---	<0.3	---
Oil and Grease (Benzene Ext.)	0.7%	0.05%	0.01%	<0.1%	34%	35%	74%	60%	62%	60%	0.04%	<0.1%	0.45%	1.1%

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(All numbers in mg/kg except where noted)

SAMPLE TYPE	API Separator Sludge		Settling Pond		Lube Oil Filter Clays		FCC Catalyst Fines		API Separator Sludge		Cooling Tower Sludge	
REFINERY CODE	B-3		B-3		C-3		C-3		C-3		C-3	
	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery	JE	Refinery
COMPONENT												
Phenols	15.2	---	---	---	6.4	---	6.4	---	3.8	---	0.6	<0.01
Cyanide	0.3	---	---	---	<0.1	---	<0.1	---	7.5	---	0.21	---
Selenium (Se)	<2	---	---	---	2.1	0.7	<1.0	0.7	<1.0	0.7	<1.0	2.0
Arsenic (As)	3.7	---	---	---	1.4	---	3.2	---	15.0	0.6	14.0	---
Mercury (Hg)	0.45	---	---	---	0.33	<0.5	0.06	<0.5	2.9	3.1	0.09	<0.5
Beryllium (Be)	<0.2	---	---	---	0.50	0.29	0.25	0.03	<0.25	---	<0.13	0.1
Vanadium (V)	7.5	---	---	---	65.0	<250	475.0	1600.0	45.0	77.0	7.5	10.0
Chromium (Cr)	102.0	270.0	687.0	860.0	45.0	37.0	95.0	47.0	252.0	<1.0	343.0	37.0
Cobalt (Co)	3.6	---	---	---	5.0	<10.0	7.8	22.0	10.5	8.1	1.3	1.0
Nickel (Ni)	16.3	---	---	---	22.0	<10.0	270.0	215.0	34.0	10.0	3.0	<1.0
Copper (Cu)	14.0	---	---	---	8.0	<5.0	62.0	71.0	550.0	751.0	363.0	225.0
Zinc (Zn)	70.0	208.0	525.0	410.0	115.0	7.6	170.0	77.0	840.0	92.0	700.0	700.0
Silver (Ag)	0.2	---	---	---	1.0	---	1.8	---	1.0	---	0.5	---
Cadmium (Cd)	0.28	---	---	---	1.5	<5.0	<0.3	<5.0	0.5	<5.0	0.3	<1.0
Lead (Pb)	9.0	20.0	15.0	18.0	<2.5	<10.0	59.0	<10.0	32.5	28.0	7.5	19.0
Molybdenum (Mo)	5.0	---	---	---	<5.0	<75.0	12.5	<75.0	5.0	<20.0	<2.5	<5.0
Ammonium Salts (As NH_4)	---	---	---	---	---	---	---	---	---	---	14.0	88.0
Benz-A-Pyrene (PNA)	<0.3	---	---	---	0.2	---	<0.5	---	2.3	---	<0.5	---
Oil and Grease (Benzene Ext.)	45.1%	---	---	---	39.8%	38.8%	0.03%	0.01%	22.3%	---	4.0%	0.01%

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APPENDIX E

SAMPLE INFORMATION SHEET
(API QUESTIONNAIRE)
(JEC Project 02-1033)

This information sheet was developed after a trial visit to a West Coast refinery, and was mailed by the API to each participating refinery. It was designed to provide certain refinery information required to carry out this industry study.

Each company was requested to nominate two or more of their refineries in different geographic areas. From the nominations, the Task Force selected 17 which best represented the sample distribution outlined by Jacobs. It was recognized that all of the seventeen refineries* selected by Jacobs Engineering Co. might not be available for the survey.

The attached Table 1-E lists the solid waste streams which may be present in the refineries. The definition of a solid waste stream in this case is any identifiable refinery waste stream (excluding trash) that is not subject to control under either air or water environmental regulations.

Instructions for Completing the Questionnaire

1. Complete the general information sheet to identify and characterize the refinery. Under products, list only the broad categories of products such as gasoline, kerosene, lubes, etc.

2. Complete a separate Solid Waste Stream Data Sheet for each solid waste stream that is disposed of offsite or onsite. Do not include such things as reformer catalyst in which the noble metal is reclaimed. Describe in general terms the principal sources of the wastes, particularly if it is a mixture of several streams. If the stream is disposed of offsite, give the name of the contractor, the cose of the offsite disposal, and if known, the location of the site of ultimate disposal.

---

*List of seventeen refineries is not included because of a confidentiality agreement with the industry.

3. Prepare a block diagram (similar to the attached sample) showing the origin of the various solid waste streams. The purpose of the diagram is to assist Jacobs in understanding the origin of the streams and their relationship to each other. Jacobs would appreciate having a copy of the wastewater flow sheet which was filed with your NPDES permit application. They should also appreciate receiving a copy of the PR brochure for the refinery usually given to visitors. The Jacobs representatives will have with them a copy of the Annual Refining Survey from the April 1, 1974, Oil and Gas Journal. They will ask if any of the units shown were not in operation at the time of the sampling. All of this information will assist Jacobs in their study of the data collected while not revealing any unpublished data concerning the processing scheme.

4. Complete the questionnaire prior to the Jacobs visit and furnish a copy to Jacobs during the visit. Arrangements for the visit will be made by Jacobs with the Refinery Contact.

5. Samples of each solid waste stream should be collected jointly with the Jacobs representatives. Duplicate samples should be collected and one of them analyzed by the refinery. After the Jacobs visit, a copy of the completed questionnaire should be furnished to the Corporate Contact who will in turn, furnish it to the Task Force Chairman.

Company Name____________________ Refinery Location__________

Solid Waste Stream Data Sheet

Identifying Name____________________ ☐ Continuous Stream

☐ Intermittent Stream

Quantity (previous 12 mo.)____________________

(monthly range) ____________________

Source (Describe)____________________

Method of Disposal (Describe)____________________

(off-site, on-site, reclaimed, costs, contractor)

Analysis (if available) :

Asbestos
Arsenic
Beryllium
Cadmium
Copper
Cyanides
Lead
Mercury
Vanadium

Nickel
PNA's
Organic Amines
Halogenated Hydrocarbons
Pesticides
Selenium
Zinc
Chromium
Other

(List of components furnished by Jacobs)

TABLE I-E

Refinery Sources of Solid Wastes

A. Utility Sludges
   Water Treatment & Power Generation Wastes

B. Waste Treatment Residue
   Bio Sludges
   DAF - Floated and Bottoms
   API Separator Bottoms
   Chemical Sludges

C. Tank Bottoms
   Crude
   Products

D. Catalyst Fines or Rejects

E. Filter Clays
   Driers
   Filters

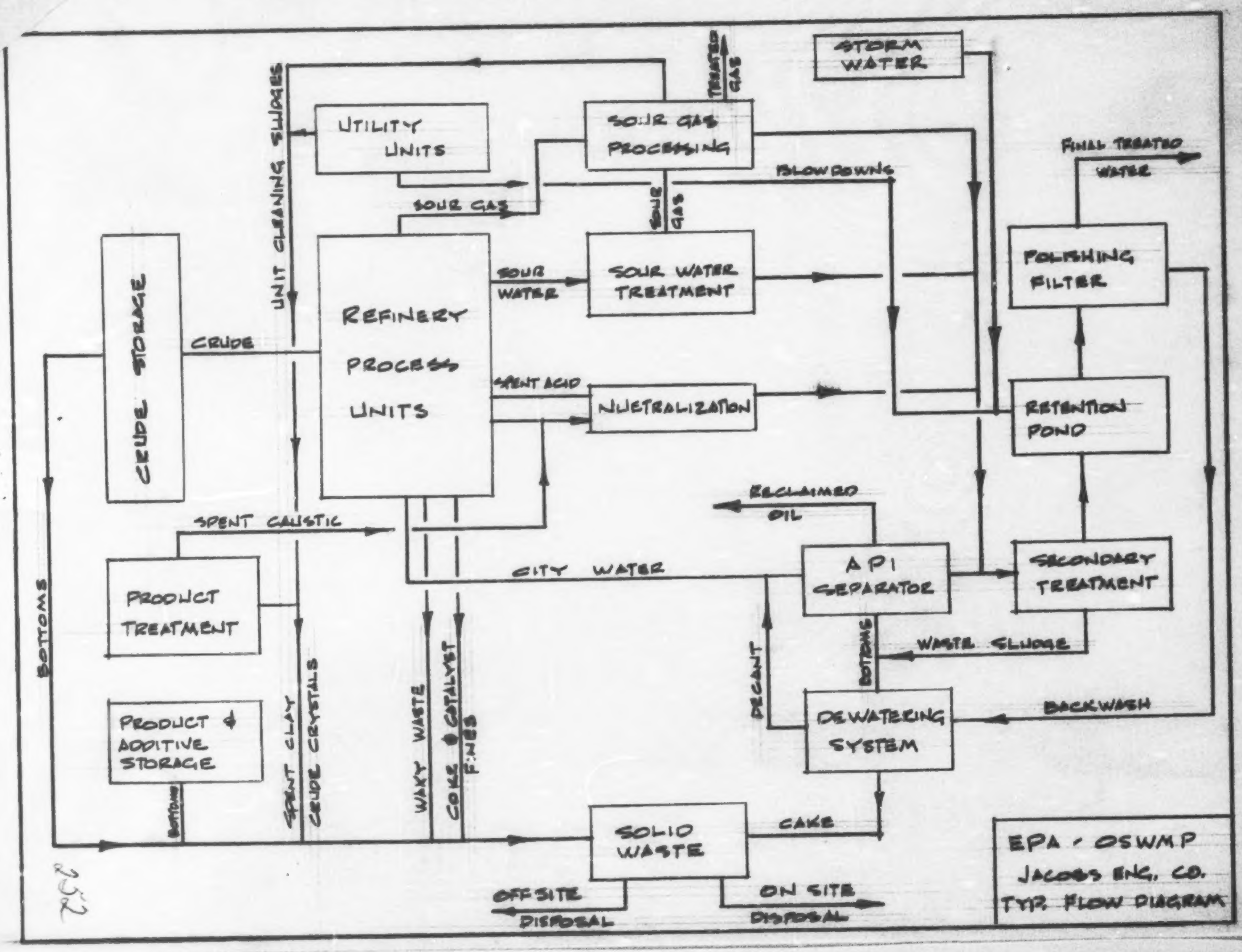
F. Process Chemical Wastes (e.g. acids & caustics)

G. Solid Incinerator Wastes

H. Cleanup, Maintenance, and Spills

I. Air Pollution Abatement Sources

J. Other

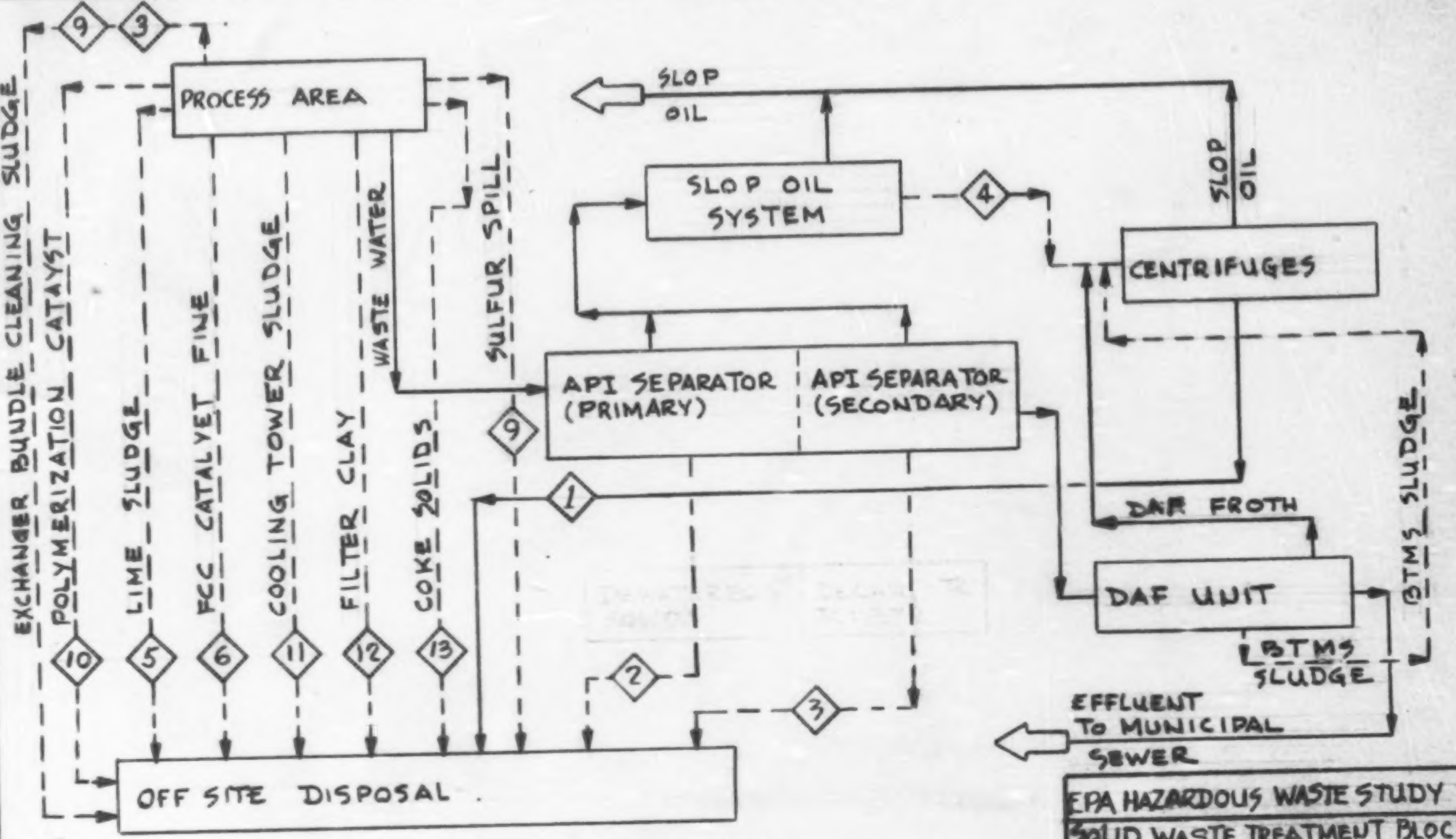

STORM WATER
UTILITY UNITS
SOUR GAS PROCESSING
TREATED GAS
UNIT CLEANING SLUDGES
SOUR GAS
BLOWDOWNS
SOUR GAS
FINAL TREATED WATER
CRUDE STORAGE
CRUDE
REFINERY PROCESS UNITS
SOUR WATER
SOUR WATER TREATMENT
POLISHING FILTER
SPENT ACID
NUETRALIZATION
RETENTION POND
RECLAIMED OIL
SPENT CAUSTIC
CITY WATER
API SEPARATOR
SECONDARY TREATMENT
PRODUCT TREATMENT
BOTTOMS
WASTE SLUDGE
BOTTOMS
DECANT
PRODUCT & ADDITIVE STORAGE
SPENT CLAY
CRUDE CRYSTALS
WAXY WASTE
COKE & CATALYST FINES
DEWATERING SYSTEM
BACKWASH
BOTTOMS
SOLID WASTE
CAKE
OFF SITE DISPOSAL
ON SITE DISPOSAL

EPA - OSWMP
JACOBS ENG. CO.
TYP. FLOW DIAGRAM

APPENDIX F

FLOW DIAGRAMS OF REFINERY SOLID WASTE TREATMENT PROCESSES AND WASTE FLOW

This Appendix contains block flow diagrams of the solid waste treatment system of each of the refineries visited in the study. These diagrams show the origin of the solid waste, the treatment processes, and the disposition of residual solid waste and sidestreams. Also shown is the type of stream, continuous or intermittent, and the sample location. The sample numbers indicate the order in which the samples were taken, and the letters identify the survey team. The refinery number completes identification of sample origin.


9
3
PROCESS AREA
SLOP OIL
SLOP OIL SYSTEM
4
CENTRIFUGES
SLOP OIL
EXCHANGER BUNDLE CLEANING SLUDGE
POLYMERIZATION CATAYST
LIME SLUDGE
FCC CATALYET FINE
COOLING TOWER SLUDGE
FILTER CLAY
WASTE WATER
COKE SOLIDS
SULFUR SPILL
9
API SEPARATOR (PRIMARY)
API SEPARATOR (SECONDARY)
1
DAF FROTH
DAF UNIT
BTMS SLUDGE
BTMS SLUDGE
10
5
6
11
12
13
2
3
EFFLUENT TO MUNICIPAL SEWER
OFF SITE DISPOSAL

LEGEND

CONTINUOUS FLOW ——————

INTERMITTENT FLOW - - - - - -

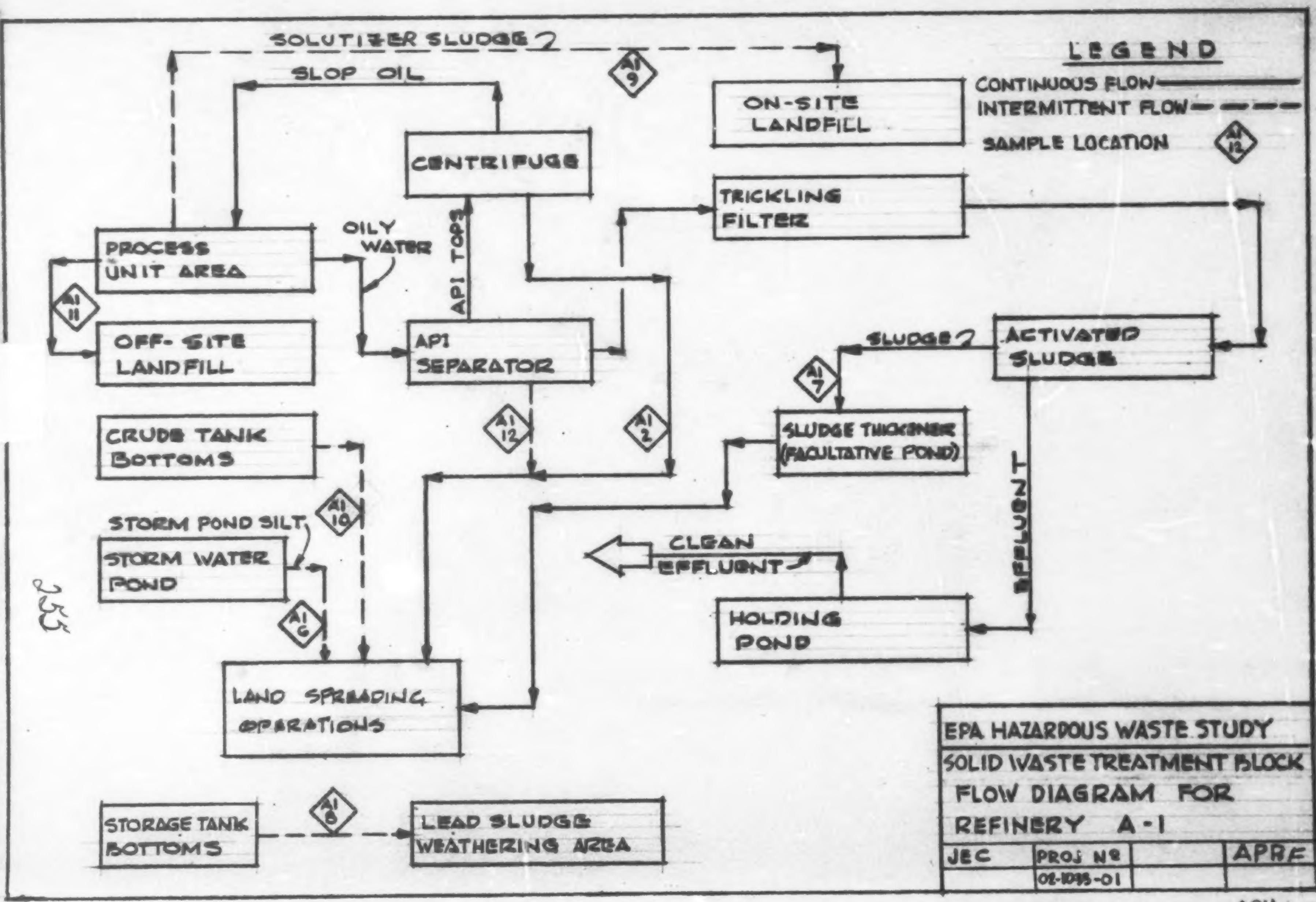
SAMPLE LOCATION ◇1

EPA HAZARDOUS WASTE STUDY

SOLID WASTE TREATMENT BLOCK

FLOW DIAGRAM FOR
REFINERY A

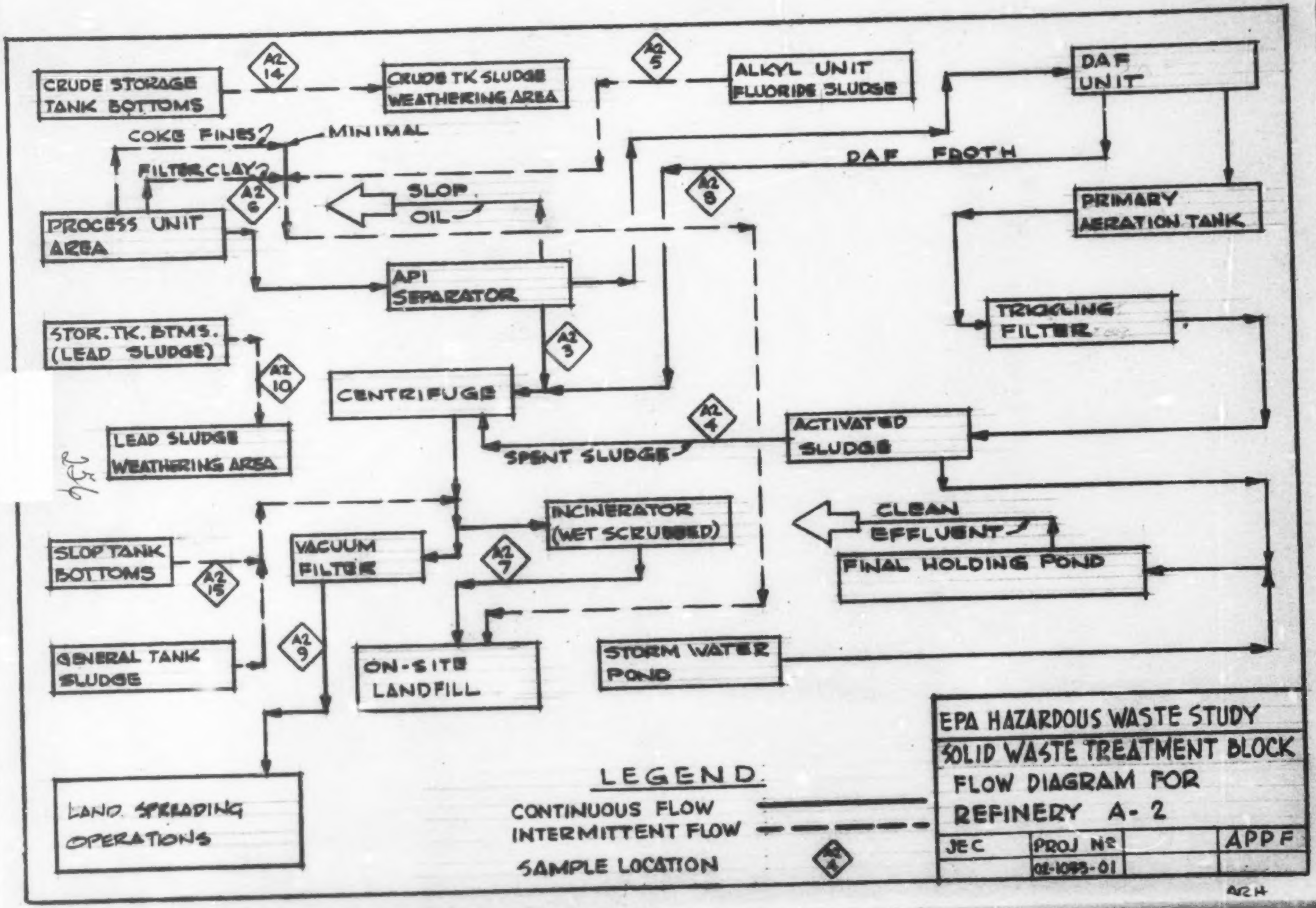
JEC	PROJ NO		APP. F
	08-1053-01		


SOLUTIZER SLUDGE ?
SLOP OIL
A1 9
ON-SITE LANDFILL
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
A1 13
CENTRIFUGE
TRICKLING FILTER
PROCESS UNIT AREA
OILY WATER
API TOPS
A1 11
OFF-SITE LANDFILL
API SEPARATOR
ACTIVATED SLUDGE
SLUDGE ?
A1 7
CRUDE TANK BOTTOMS
A1 12
A1 2
SLUDGE THICKENER (FACULTATIVE POND)
EFFLUENT
STORM POND SILT
A1 10
STORM WATER POND
CLEAN EFFLUENT
A1 6
HOLDING POND
LAND SPREADING OPERATIONS
STORAGE TANK BOTTOMS
A1 8
LEAD SLUDGE WEATHERING AREA

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY A-1

JEC	PROJ Nº		APR/E
	02-1035-01		

AR14


CRUDE STORAGE TANK BOTTOMS
A2 14
CRUDE TK SLUDGE WEATHERING AREA
A2 5
ALKYL UNIT FLUORIDE SLUDGE
DAF UNIT
COKE FINES?
MINIMAL
FILTER CLAY?
A2 6
SLOP OIL
DAF FROTH
A2 8
PRIMARY AERATION TANK
PROCESS UNIT AREA
API SEPARATOR
TRICKLING FILTER
STOR. TK. BTMS. (LEAD SLUDGE)
A2 3
A2 10
CENTRIFUGE
A2 4
ACTIVATED SLUDGE
LEAD SLUDGE WEATHERING AREA
SPENT SLUDGE
INCINERATOR (WET SCRUBBED)
CLEAN EFFLUENT
SLOP TANK BOTTOMS
VACUUM FILTER
A2 7
FINAL HOLDING POND
A2 15
GENERAL TANK SLUDGE
A2 9
ON-SITE LANDFILL
STORM WATER POND
LAND SPREADING OPERATIONS
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
A2 4

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY A- 2

JEC	PROJ №	APPF
	02-1083-01	

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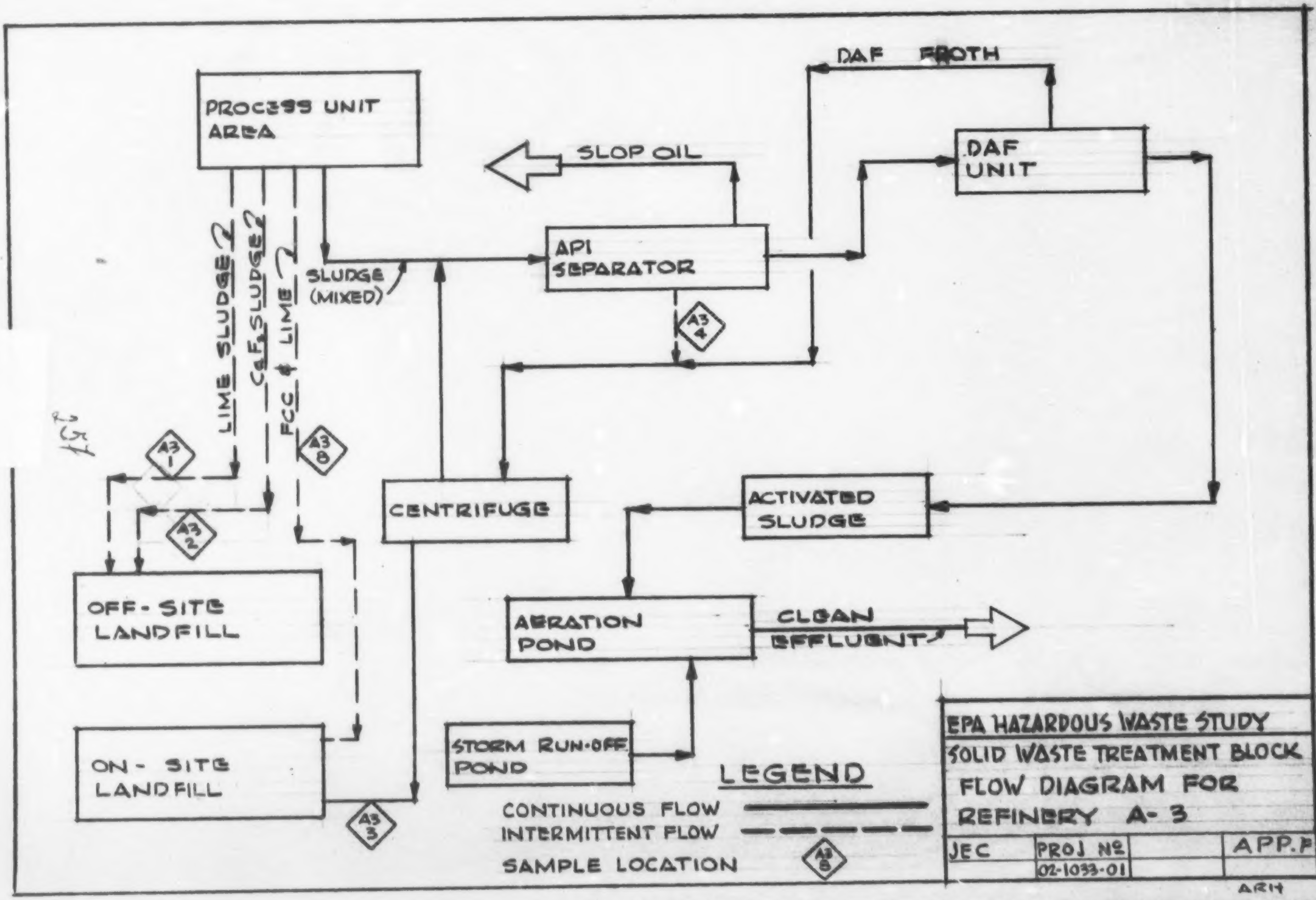

PROCESS UNIT AREA
LIME SLUDGE ?
CaF2 SLUDGE ?
FCC & LIME ?
SLUDGE (MIXED)
SLOP OIL
API SEPARATOR
DAF FROTH
DAF UNIT
A3 1
A3 2
A3 3
A3 4
A3 8
CENTRIFUGE
ACTIVATED SLUDGE
OFF-SITE LANDFILL
ON-SITE LANDFILL
AERATION POND
CLEAN EFFLUENT
STORM RUN-OFF POND

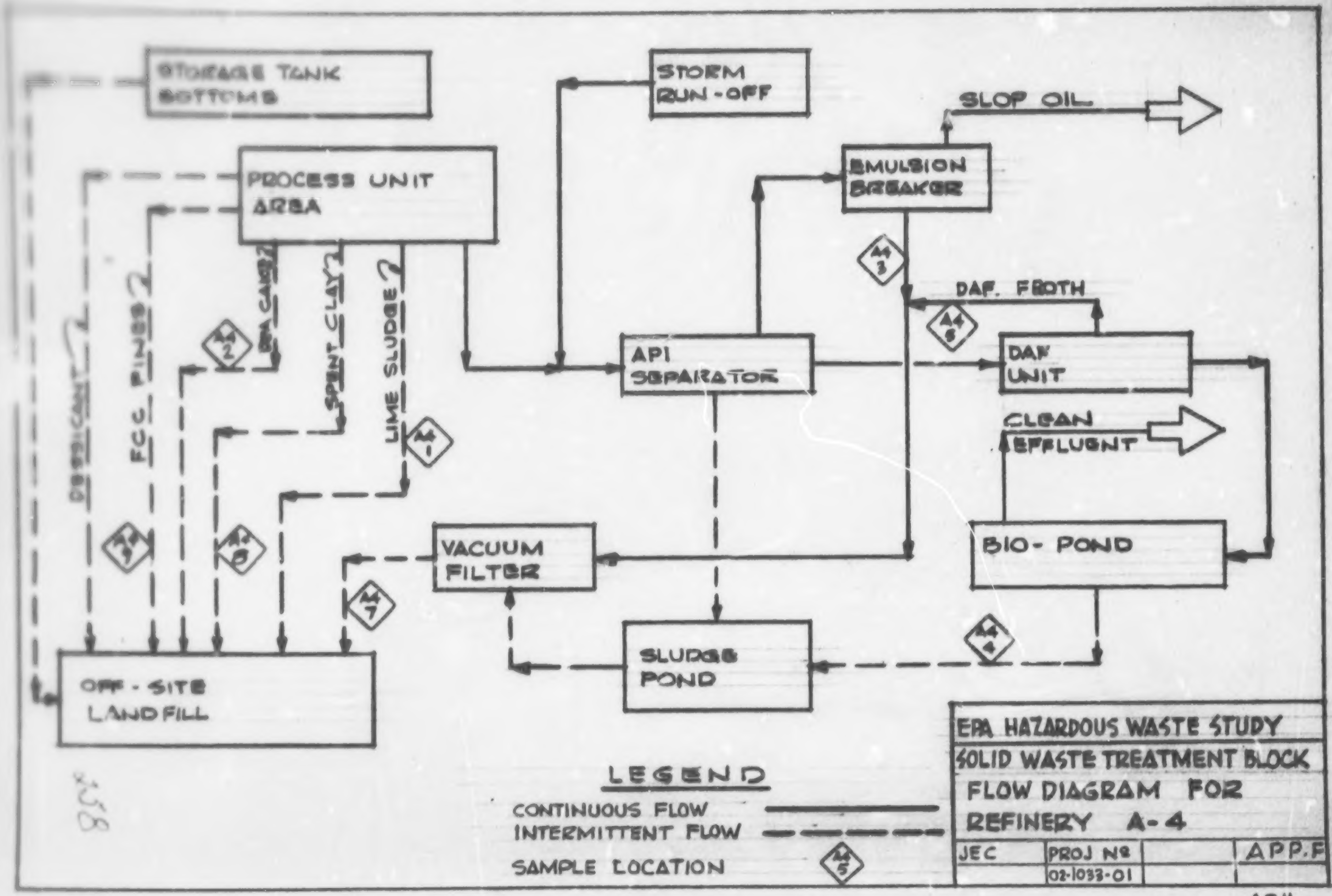
LEGEND

CONTINUOUS FLOW ——————
INTERMITTENT FLOW — — — — —
SAMPLE LOCATION ◇ A3 8

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY A-3

JEC	PROJ No 02-1033-01		APP. F

AR14


STORAGE TANK BOTTOMS
STORM RUN-OFF
SLOP OIL
PROCESS UNIT AREA
EMULSION BREAKER
DESSICANT ?
FCC FINES ?
EPA CAKE ?
SPENT CLAY ?
LIME SLUDGE ?
A4 3
DAF. FROTH
A4 2
A4 1
A4 5
API SEPARATOR
DAF UNIT
CLEAN EFFLUENT
A4 9
A4 8
VACUUM FILTER
BIO-POND
A4 7
A4 4
OFF-SITE LANDFILL
SLUDGE POND
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
A4 5

EPA HAZARDOUS WASTE STUDY

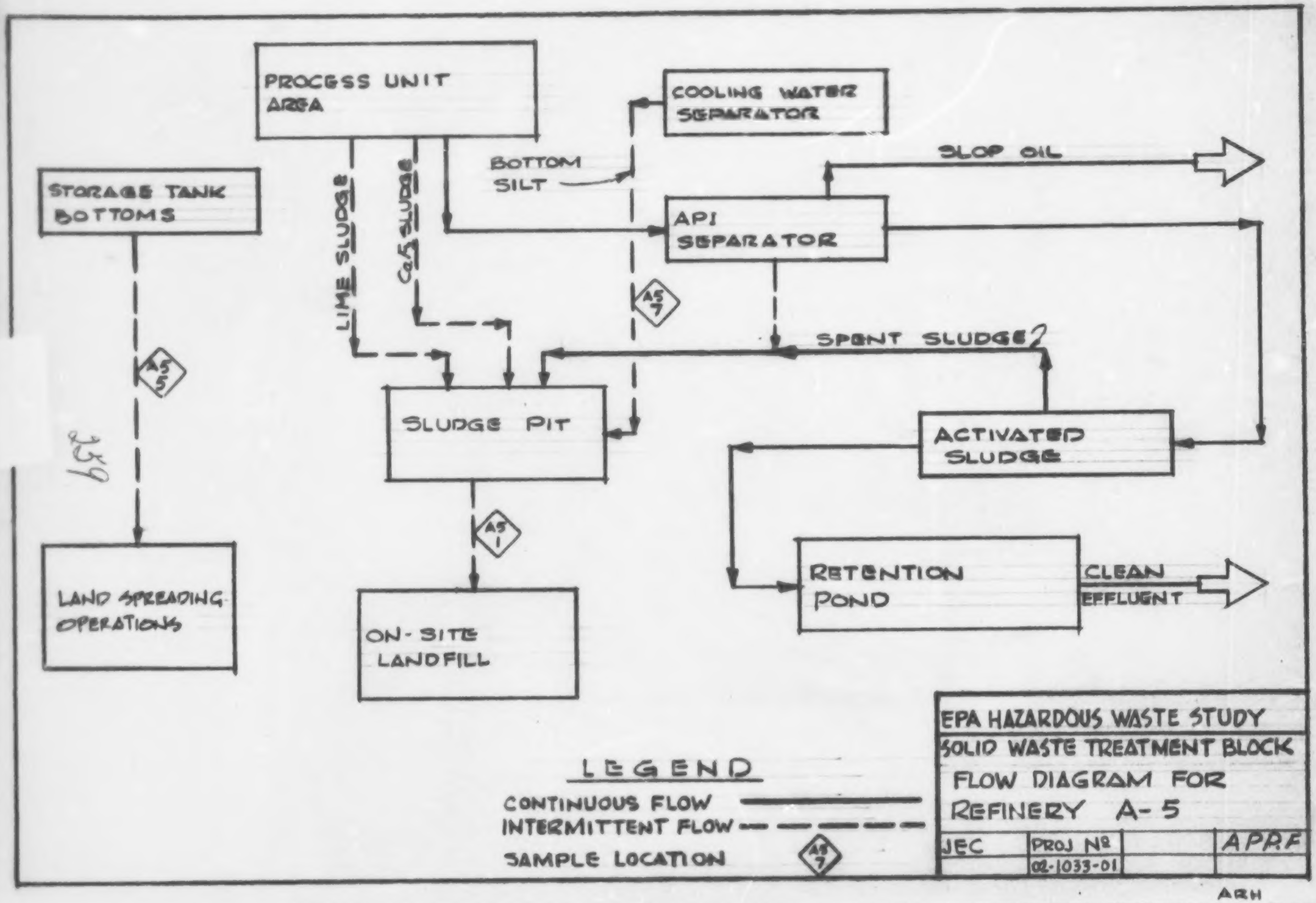
SOLID WASTE TREATMENT BLOCK

FLOW DIAGRAM FOR

REFINERY A-4

JEC	PROJ Nº 02-1033-01		APP. F

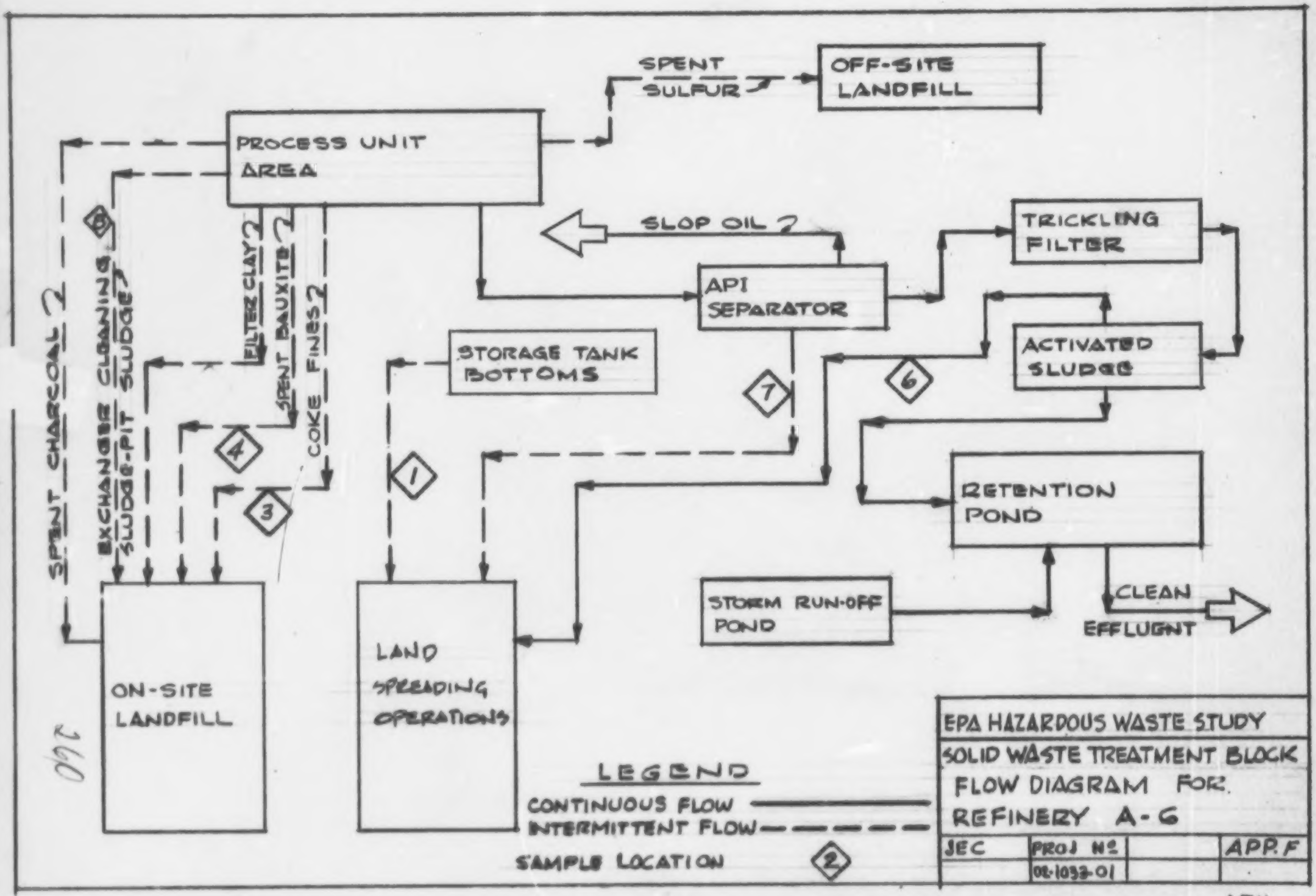
ARH


PROCESS UNIT AREA
COOLING WATER SEPARATOR
BOTTOM SILT
SLOP OIL
STORAGE TANK BOTTOMS
LIME SLUDGE
CaS SLUDGE
API SEPARATOR
A5 7
SPENT SLUDGE?
A5 5
SLUDGE PIT
ACTIVATED SLUDGE
A5 1
LAND SPREADING OPERATIONS
ON-SITE LANDFILL
RETENTION POND
CLEAN EFFLUENT
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
A5 7

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY A-5

JEC	PROJ Nº 02-1033-01		APRF

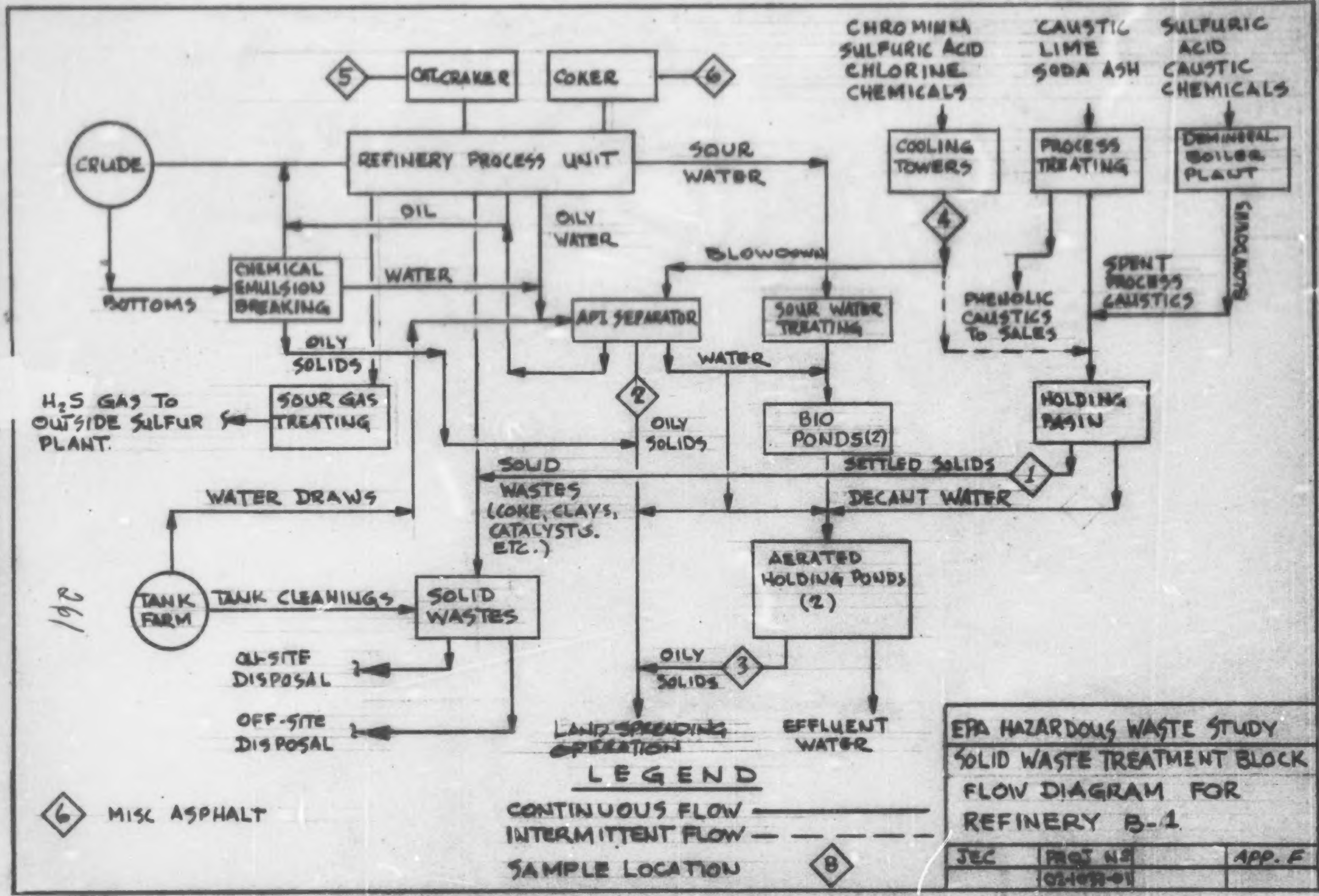
ARH


SPENT SULFUR
OFF-SITE LANDFILL
PROCESS UNIT AREA
SLOP OIL
TRICKLING FILTER
API SEPARATOR
ACTIVATED SLUDGE
STORAGE TANK BOTTOMS
SPENT CHARCOAL
5
EXCHANGER CLEANING SLUDGE-PIT SLUDGE
FILTER CLAY
SPENT BAUXITE
COKE FINES
4
3
1
7
6
RETENTION POND
ON-SITE LANDFILL
LAND SPREADING OPERATIONS
STORM RUN-OFF POND
CLEAN EFFLUENT
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
2

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY A-6

JEC	PROJ NO 08-1033-01		APP. F

ARH

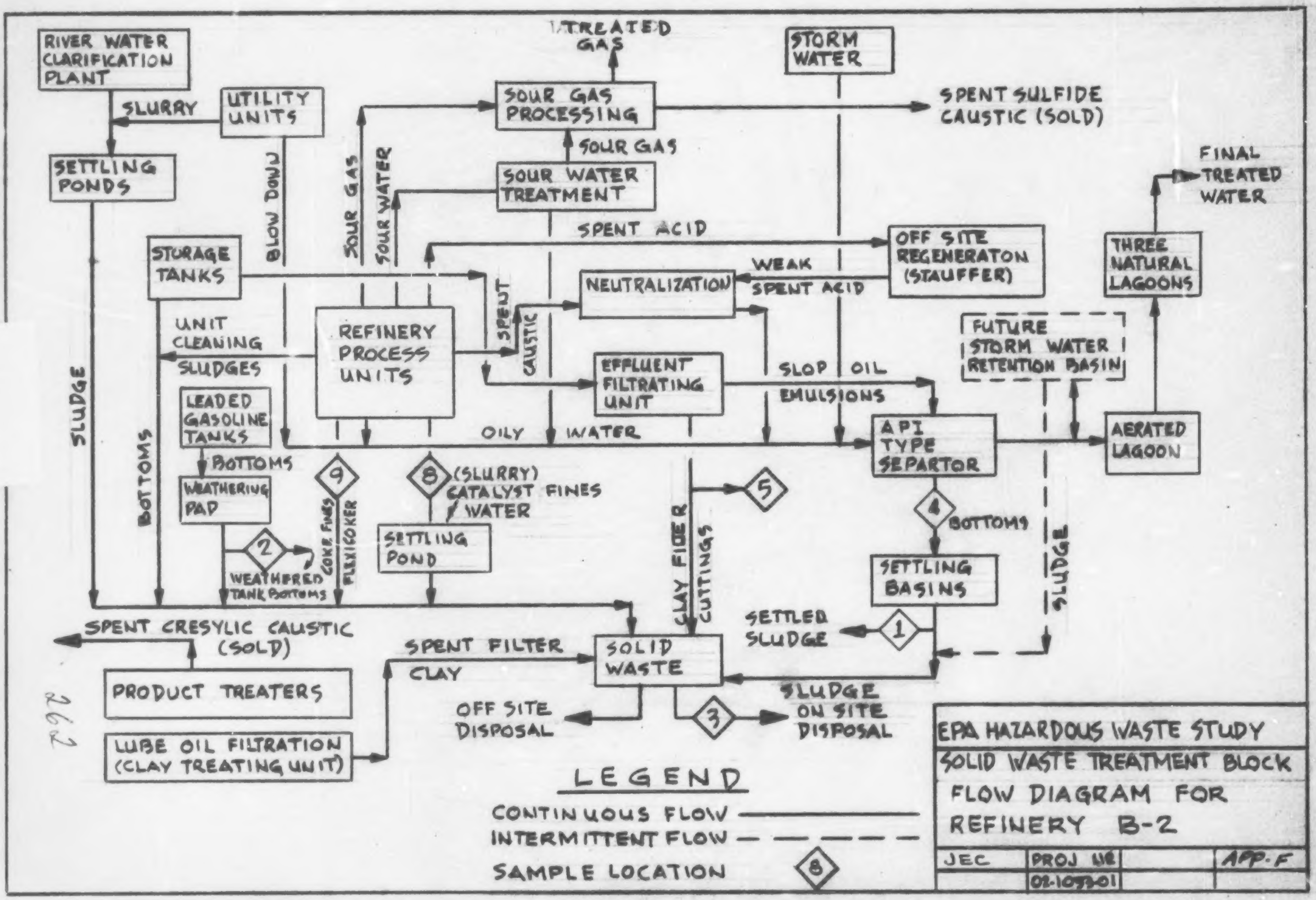

CRUDE
BOTTOMS
CAT.CRAKER
COKER
5
6
REFINERY PROCESS UNIT
SOUR WATER
OIL
OILY WATER
WATER
CHEMICAL EMULSION BREAKING
OILY SOLIDS
SOUR GAS TREATING
H2S GAS TO OUTSIDE SULFUR PLANT.
API SEPARATOR
2
OILY SOLIDS
BLOWDOWN
WATER
SOUR WATER TREATING
BIO PONDS(2)
CHROMINMA SULFURIC ACID CHLORINE CHEMICALS
COOLING TOWERS
4
CAUSTIC LIME SODA ASH
PROCESS TREATING
PHENOLIC CAUSTICS TO SALES
SULFURIC ACID CAUSTIC CHEMICALS
DEMINERAL. BOILER PLANT
BLOWDOWNS
SPENT PROCESS CAUSTICS
HOLDING BASIN
1
SETTLED SOLIDS
DECANT WATER
SOLID WASTES (COKE, CLAYS, CATALYSTS. ETC.)
WATER DRAWS
TANK FARM
TANK CLEANINGS
SOLID WASTES
ON-SITE DISPOSAL
OFF-SITE DISPOSAL
AERATED HOLDING PONDS (2)
3
OILY SOLIDS
~~LAND SPREADING OPERATION~~
EFFLUENT WATER
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8
6 MISC ASPHALT

EPA HAZARDOUS WASTE STUDY

SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY B-1

JEC	PROJ NO		APP. F
	[illegible]		

261


RIVER WATER CLARIFICATION PLANT
SLURRY
UTILITY UNITS
SETTLING PONDS
BLOW DOWN
SOUR GAS
SOUR WATER
TREATED GAS
SOUR GAS PROCESSING
SOUR GAS
SOUR WATER TREATMENT
STORM WATER
SPENT SULFIDE CAUSTIC (SOLD)
FINAL TREATED WATER
SPENT ACID
STORAGE TANKS
OFF SITE REGENERATON (STAUFFER)
THREE NATURAL LAGOONS
NEUTRALIZATION
WEAK SPENT ACID
UNIT CLEANING SLUDGES
REFINERY PROCESS UNITS
SPENT CAUSTIC
FUTURE STORM WATER RETENTION BASIN
EFFLUENT FILTRATING UNIT
SLOP OIL
EMULSIONS
SLUDGE
LEADED GASOLINE TANKS
OILY WATER
API TYPE SEPARTOR
AERATED LAGOON
BOTTOMS
9
8
(SLURRY) CATALYST FINES / WATER
5
WEATHERING PAD
COKE FINES
FLEXICOKER
SETTLING POND
CLAY FIBER
CUTTINGS
4
BOTTOMS
BOTTOMS
2
WEATHERED TANK BOTTOMS
SETTLING BASINS
SLUDGE
SETTLED SLUDGE
1
SPENT CRESYLIC CAUSTIC (SOLD)
SPENT FILTER CLAY
SOLID WASTE
PRODUCT TREATERS
SLUDGE ON SITE DISPOSAL
3
OFF SITE DISPOSAL
LUBE OIL FILTRATION (CLAY TREATING UNIT)
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8

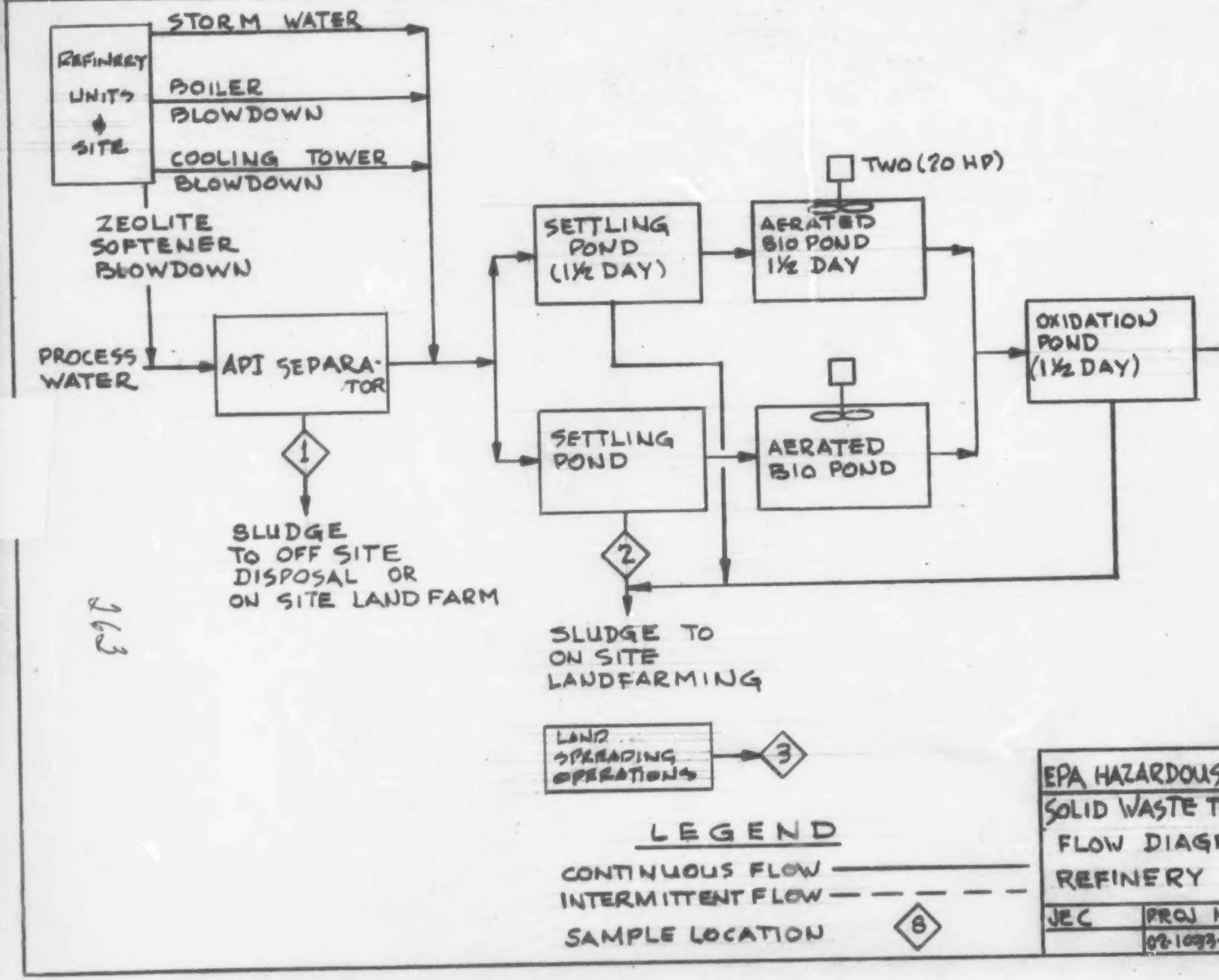
EPA HAZARDOUS WASTE STUDY

SOLID WASTE TREATMENT BLOCK

FLOW DIAGRAM FOR

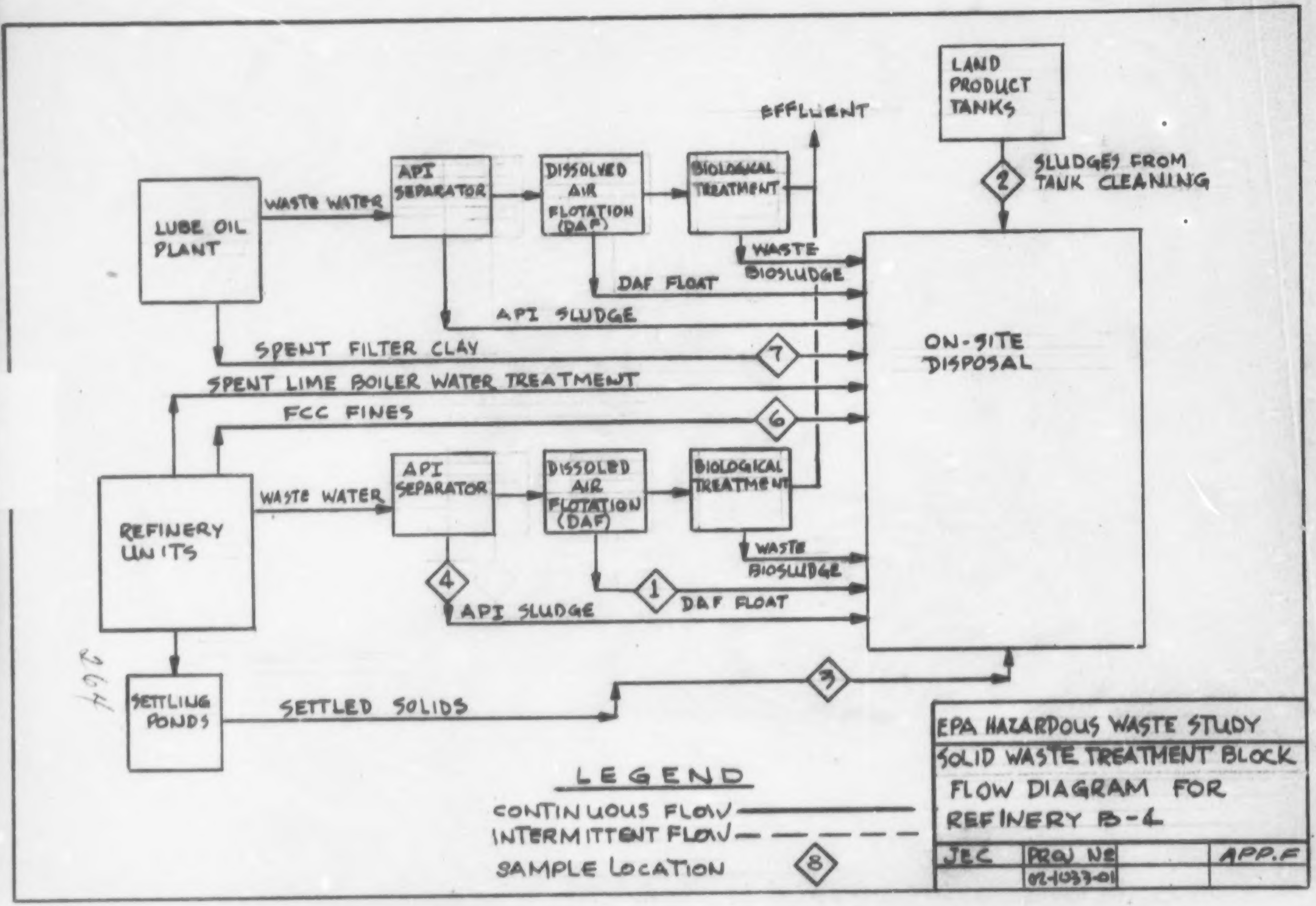
REFINERY B-2

JEC	PROJ NO		APP. F
	02-1053-01		


REFINERY UNITS & SITE
STORM WATER
BOILER BLOWDOWN
COOLING TOWER BLOWDOWN
ZEOLITE SOFTENER BLOWDOWN
PROCESS WATER
API SEPARATOR
1
SLUDGE TO OFF SITE DISPOSAL OR ON SITE LAND FARM
SETTLING POND (1½ DAY)
SETTLING POND
TWO (20 HP)
AERATED BIO POND 1½ DAY
AERATED BIO POND
2
SLUDGE TO ON SITE LANDFARMING
OXIDATION POND (1½ DAY)
EFFLUENT TO MISSISSIPPI
LAND SPREADING OPERATIONS
3
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8

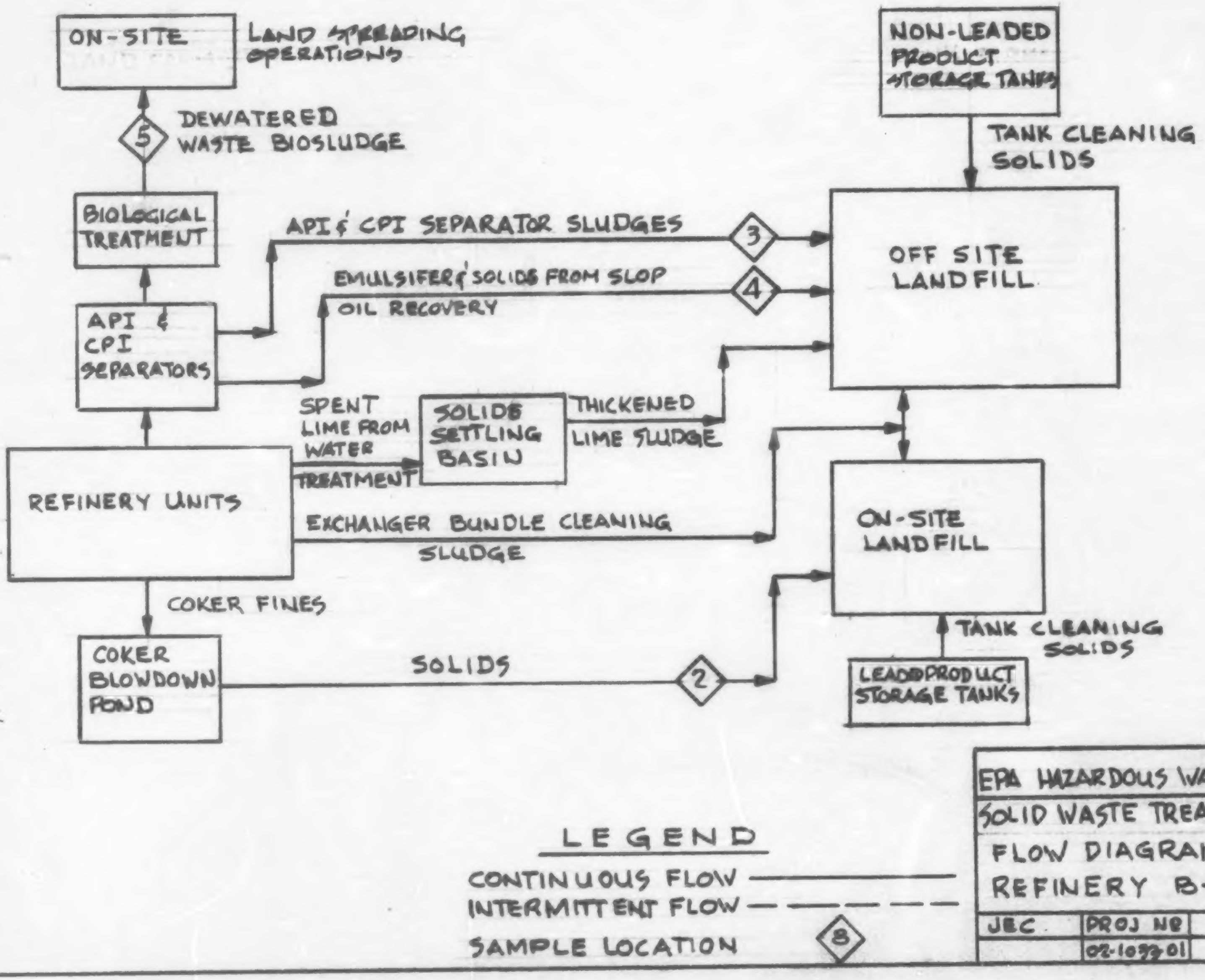
EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY B-3

JEC	PROJ NO		APP. F
	02-1093-01		


LAND PRODUCT TANKS
EFFLUENT
SLUDGES FROM TANK CLEANING
2
LUBE OIL PLANT
WASTE WATER
API SEPARATOR
DISSOLVED AIR FLOTATION (DAF)
BIOLOGICAL TREATMENT
WASTE BIOSLUDGE
DAF FLOAT
API SLUDGE
SPENT FILTER CLAY
7
ON-SITE DISPOSAL
SPENT LIME BOILER WATER TREATMENT
FCC FINES
6
REFINERY UNITS
WASTE WATER
API SEPARATOR
DISSOLED AIR FLOTATION (DAF)
BIOLOGICAL TREATMENT
WASTE BIOSLUDGE
4
API SLUDGE
1
DAF FLOAT
SETTLING PONDS
SETTLED SOLIDS
3
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8

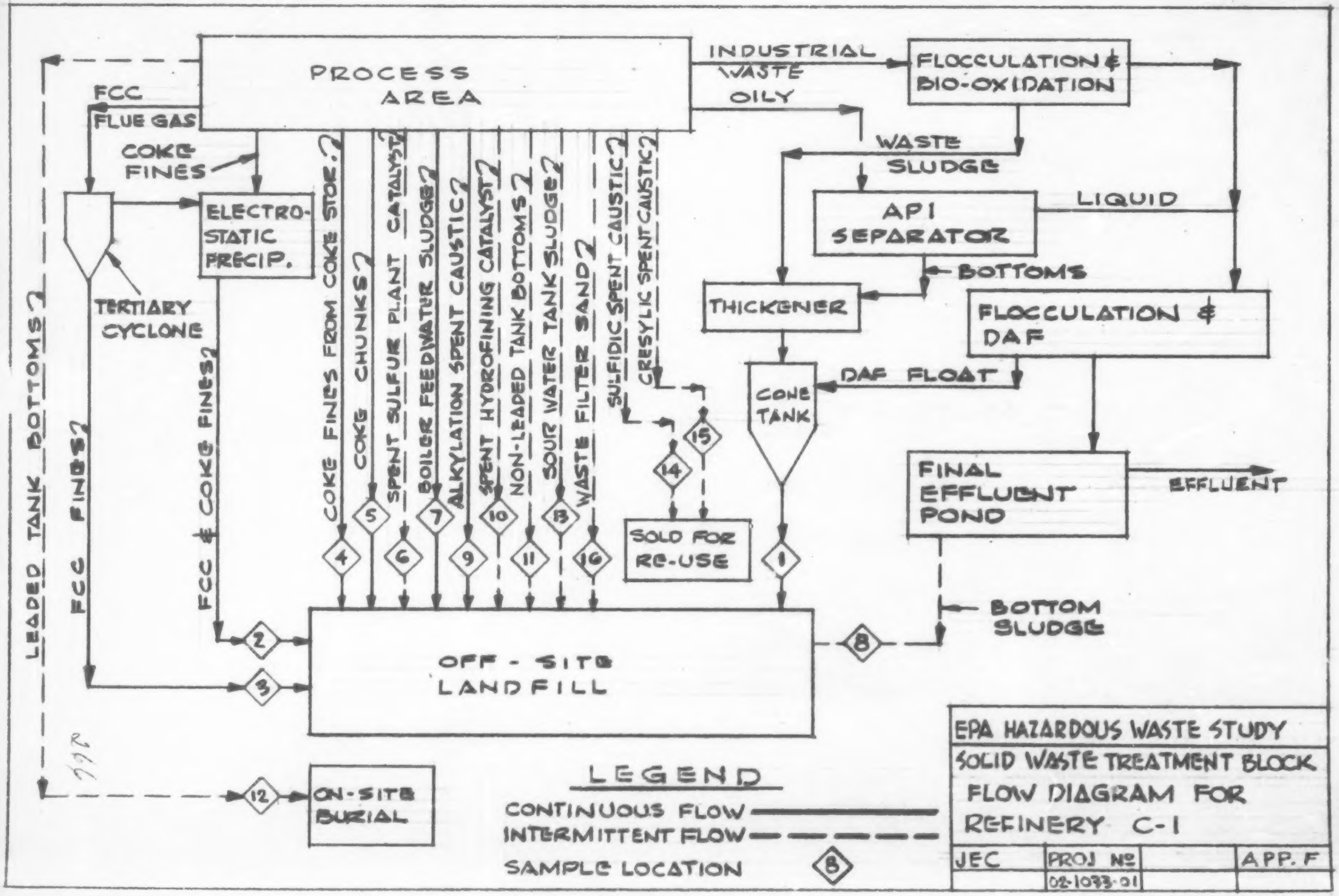
EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY B-4

JEC	PROJ NO		APP.F
	02-1033-01		


ON-SITE
LAND SPREADING OPERATIONS
DEWATERED WASTE BIOSLUDGE
5
BIOLOGICAL TREATMENT
API & CPI SEPARATORS
API & CPI SEPARATOR SLUDGES
3
EMULSIFER & SOLIDS FROM SLOP OIL RECOVERY
4
REFINERY UNITS
SPENT LIME FROM WATER TREATMENT
SOLIDS SETTLING BASIN
THICKENED LIME SLUDGE
EXCHANGER BUNDLE CLEANING SLUDGE
COKER FINES
COKER BLOWDOWN POND
SOLIDS
2
NON-LEADED PRODUCT STORAGE TANKS
TANK CLEANING SOLIDS
OFF SITE LANDFILL
ON-SITE LANDFILL
TANK CLEANING SOLIDS
LEADED PRODUCT STORAGE TANKS
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY B-5

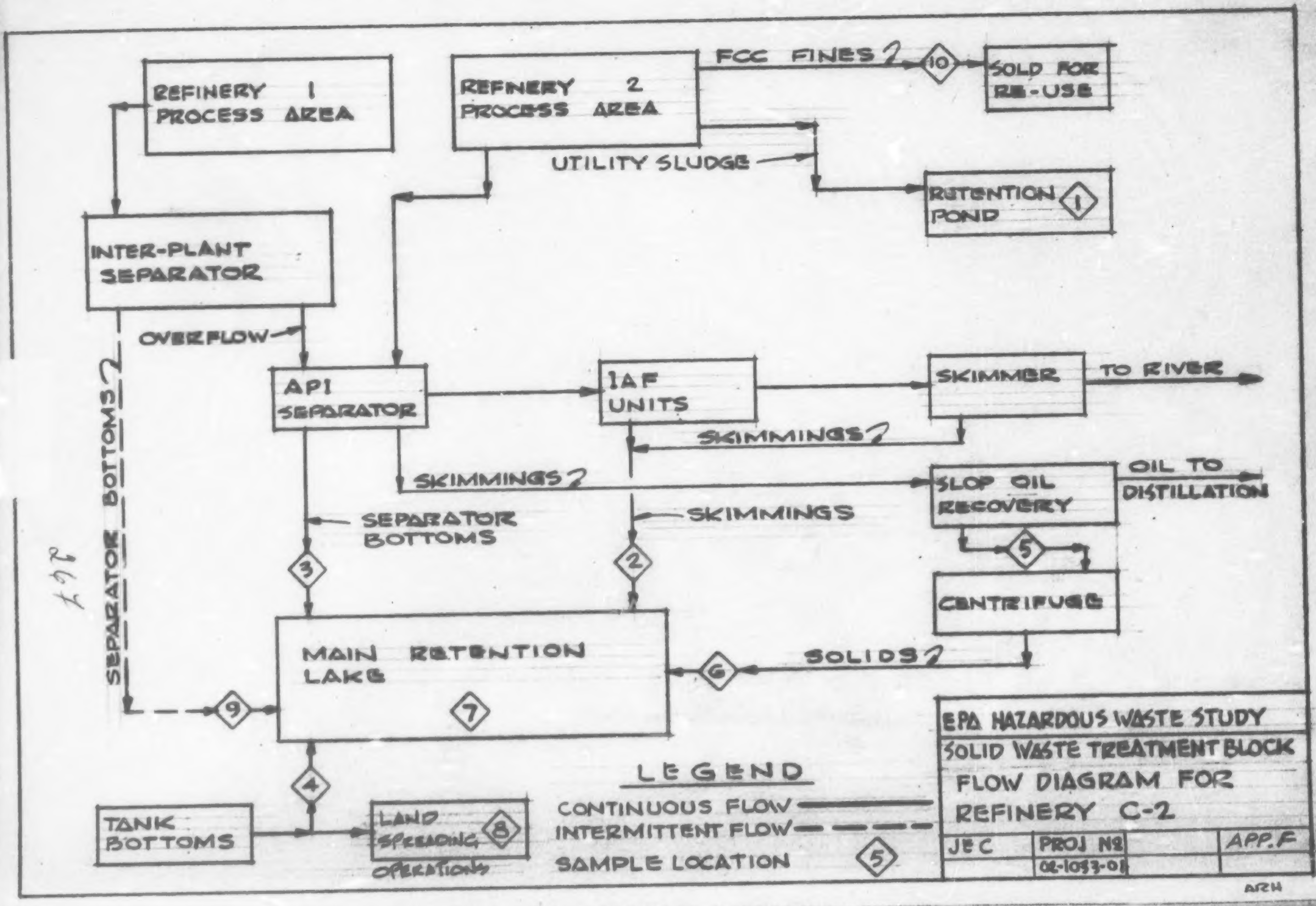
JEC	PROJ NO		APP.F
	02-1093-01		


PROCESS AREA
INDUSTRIAL WASTE
OILY
FLOCCULATION & BIO-OXIDATION
WASTE SLUDGE
API SEPARATOR
LIQUID
BOTTOMS
THICKENER
FLOCCULATION & DAF
DAF FLOAT
CONE TANK
FINAL EFFLUENT POND
EFFLUENT
BOTTOM SLUDGE
FCC FLUE GAS
COKE FINES
ELECTRO-STATIC PRECIP.
TERTIARY CYCLONE
LEADED TANK BOTTOMS
FCC FINES
FCC & COKE FINES
COKE FINES FROM COKE STORE
COKE CHUNKS
SPENT SULFUR PLANT CATALYST
BOILER FEEDWATER SLUDGE
ALKYLATION SPENT CAUSTIC
SPENT HYDROFINING CATALYST
NON-LEADED TANK BOTTOMS
SOUR WATER TANK SLUDGE
WASTE FILTER SAND
SULFIDIC SPENT CAUSTIC
CRESYLIC SPENT CAUSTIC
SOLD FOR RE-USE
OFF - SITE LANDFILL
ON-SITE BURIAL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
8

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY C-1

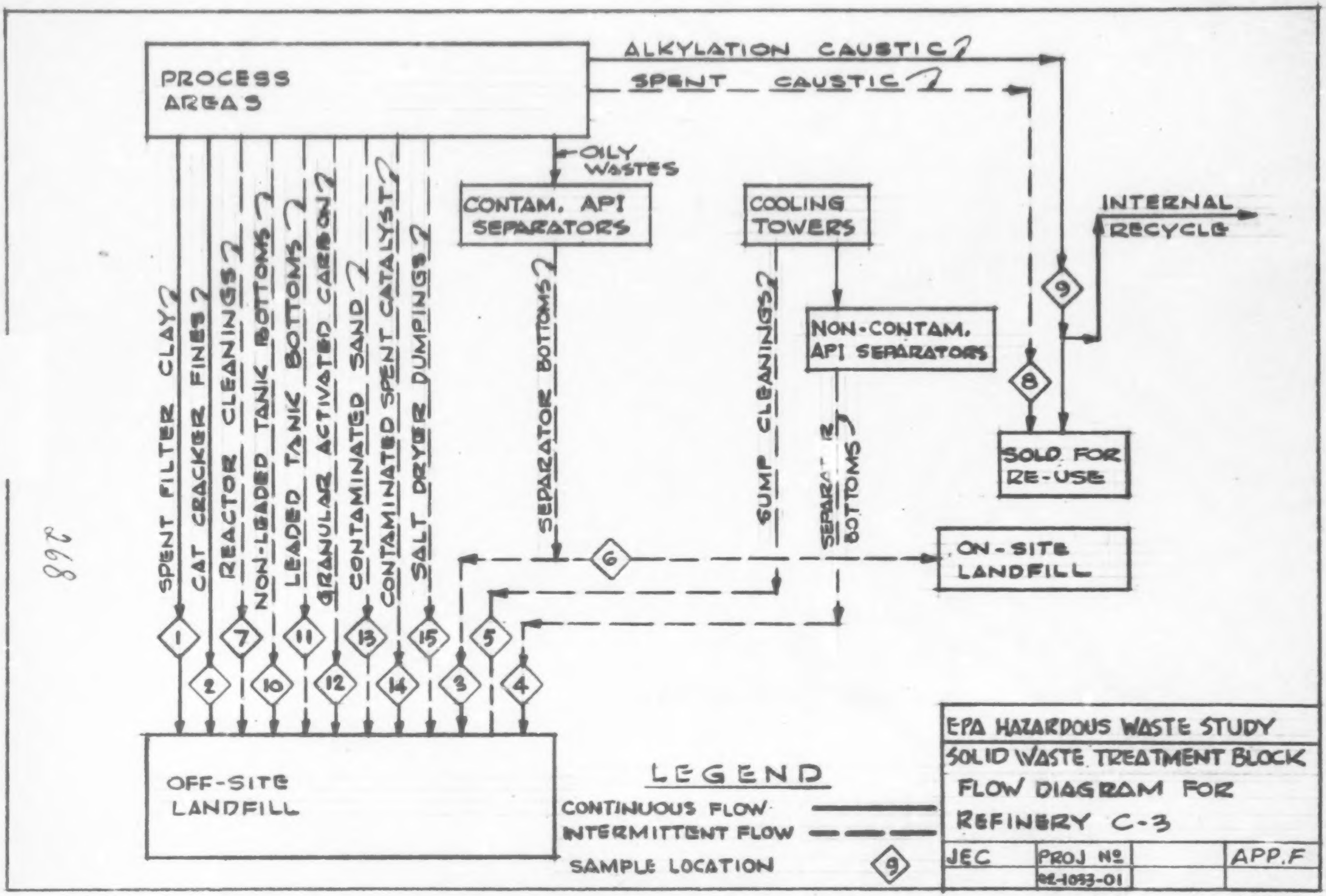
JEC	PROJ No 02-1033-01		APP. F

ARH


REFINERY 1 PROCESS AREA
REFINERY 2 PROCESS AREA
FCC FINES ?
10
SOLD FOR RE-USE
UTILITY SLUDGE
RETENTION POND
1
INTER-PLANT SEPARATOR
OVERFLOW
SEPARATOR BOTTOMS ?
API SEPARATOR
IAF UNITS
SKIMMER
TO RIVER
SKIMMINGS ?
SKIMMINGS ?
SLOP OIL RECOVERY
OIL TO DISTILLATION
SEPARATOR BOTTOMS
SKIMMINGS
3
2
5
CENTRIFUGE
MAIN RETENTION LAKE
7
6
SOLIDS ?
9
4
TANK BOTTOMS
LAND SPREADING OPERATIONS
8
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
5
ARH

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY C-2

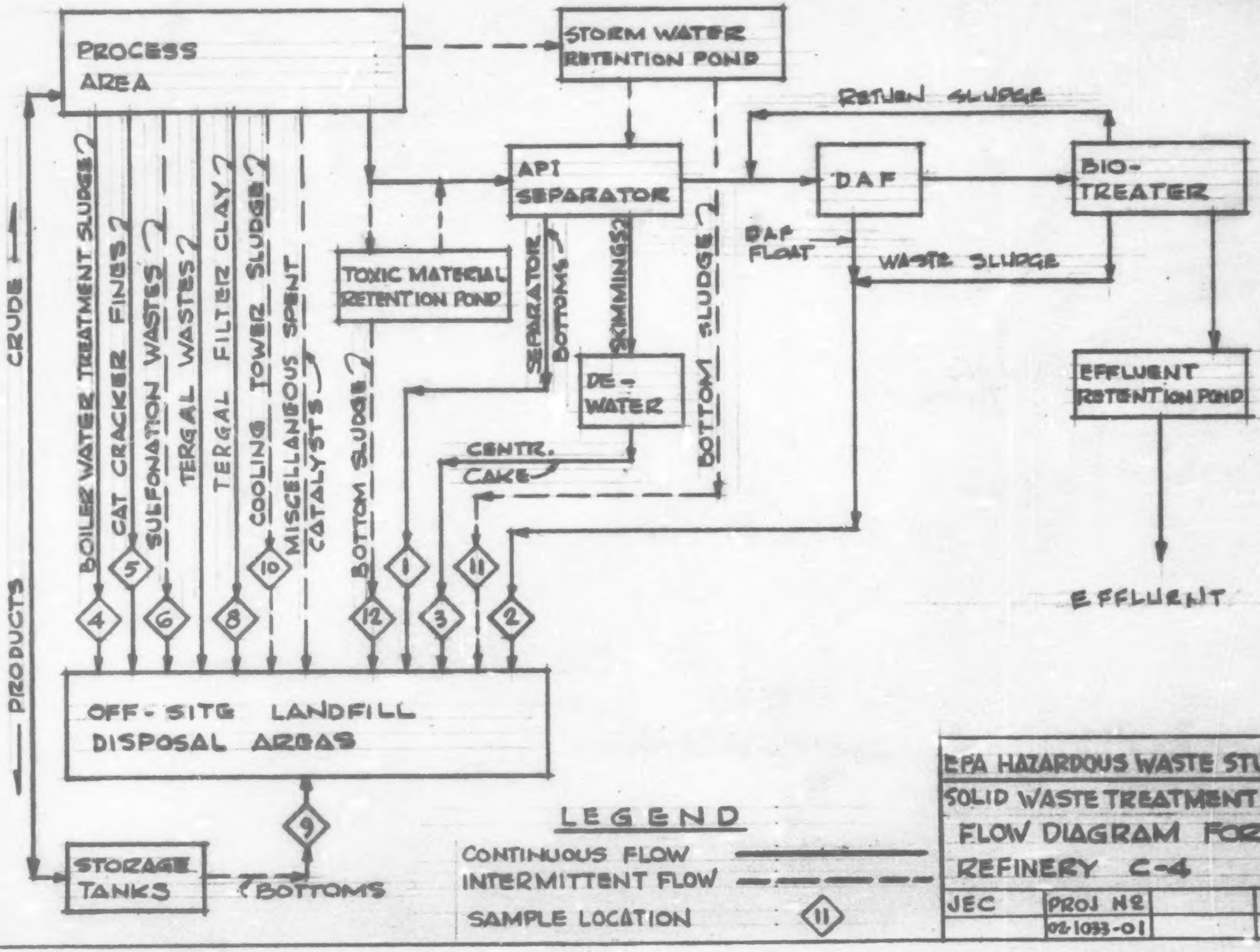
JEC	PROJ No 02-1033-01		APP. F


PROCESS AREAS
ALKYLATION CAUSTIC ?
SPENT CAUSTIC ?
OILY WASTES
CONTAM. API SEPARATORS
COOLING TOWERS
NON-CONTAM. API SEPARATORS
INTERNAL RECYCLE
SOLD FOR RE-USE
ON-SITE LANDFILL
SPENT FILTER CLAY ?
CAT CRACKER FINES ?
REACTOR CLEANINGS ?
NON-LEADED TANK BOTTOMS ?
LEADED TANK BOTTOMS ?
GRANULAR ACTIVATED CARBON ?
CONTAMINATED SAND ?
CONTAMINATED SPENT CATALYST ?
SALT DRYER DUMPINGS ?
SEPARATOR BOTTOMS ?
SUMP CLEANINGS ?
SEPARATOR BOTTOMS ?
1
2
7
10
11
12
13
14
15
3
5
4
6
8
9
OFF-SITE LANDFILL
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
9

EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY C-3

JEC	PROJ № 82-1033-01	APP. F

ARH


PROCESS AREA
STORM WATER RETENTION POND
API SEPARATOR
DAF
BIO-TREATER
RETURN SLUDGE
TOXIC MATERIAL RETENTION POND
SEPARATOR BOTTOMS
SKIMMINGS
BOTTOM SLUDGE
DAF FLOAT
WASTE SLUDGE
DE-WATER
EFFLUENT RETENTION POND
CENTR. CAKE
EFFLUENT
CRUDE
PRODUCTS
BOILER WATER TREATMENT SLUDGE
CAT CRACKER FINES
SULFONATION WASTES
TERGAL WASTES
TERGAL FILTER CLAY
COOLING TOWER SLUDGE
MISCELLANEOUS SPENT CATALYSTS
BOTTOM SLUDGE
4
5
6
8
10
12
1
3
11
2
OFF-SITE LANDFILL DISPOSAL AREAS
9
STORAGE TANKS
BOTTOMS
LEGEND
CONTINUOUS FLOW
INTERMITTENT FLOW
SAMPLE LOCATION
11

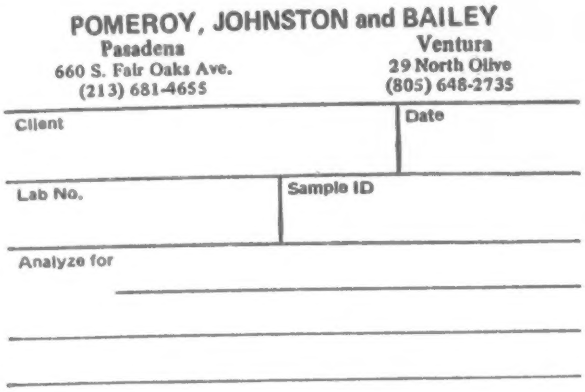
EPA HAZARDOUS WASTE STUDY
SOLID WASTE TREATMENT BLOCK
FLOW DIAGRAM FOR
REFINERY C-4
JEC
PROJ Nº
02-1033-01
APP. F

ARH

APPENDIX G

SAMPLING INSTRUCTIONS ISSUED TO PARTICIPATING REFINERIES

1. Each sample container will have a label (see below) affixed.



POMEROY, JOHNSTON and BAILEY

Pasadena
660 S. Fair Oaks Ave.
(213) 681-4655

Ventura
29 North Olive
(805) 648-2735

Client

Date

Lab No.

Sample ID

Analyze for

On the label enter the following information:

Client	Enter Project No. (02-1033)
Date	Enter date sample was taken
Lab. No.	Leave blank
Sample ID	Enter identification code
Analyze for	Use this space for any additional identity data

2. In addition to filling out the label, maintain a log on each sample. As a minimum, the following information should be recorded:

   2.1 Sample origin (where taken)

   2.2 When taken

   2.3 Type of sample (i.e., grab sample, composite sample, etc.)

   2.4 History of the sample (i.e., is the sample an accumulation over a period of time, or is it a recurring daily/weekly waste that may be variable)

3. Obtaining Representative Samples

The obtaining of homogeneous samples that are truly representative of an entire operation will, no doubt, be difficult in some cases, and impossible in others.

In the case of liquid or semi-solid wastes, a procedure of taking numerous small grab samples over a period of time will yield a more representative sample.

For dusts (such as catalyst fines) or other solids, it is recommended that a large (50 lbs. or more) sample be taken. The sample is to be thoroughly mixed by means of a shovel or trowel. After mixing, the sample is "quartered". Three of the "quarters" are discarded and the mixing and quartering is continued until the sample is reduced to the desired size.

For sizable solids, no firm recommendation can be made and each situation must be judged on its own merits.

4. Splitting the Samples

The refineries may wish to run all or part of the analyses on the same samples. To assure that analytical results can be compared, it is essential that the samples be as nearly identical as possible.

For all the cases in (3) above, it is suggested that the samples be taken in a large container, thoroughly mixed, and then divided.

Your team will be provided with sufficient one-gallon plastic sample containers, but you will not have an excess. Let the refineries provide their own sample containers (make a note of what type they are using). DO NOT give away our containers.

5. Shipping

After taking and properly labeling the samples, put each in the plastic bag (provided) and seal.

Wherever possible, ship via UPS "Blue Label" service to the Pasadena address shown on the labels.

If no UPS service is available, use Air Freight.

APPENDIX H

CHARACTERIZATION OF SPECIFIC SOLID WASTE STREAMS

This appendix is included to enable the general reader to obtain a clearer concept of the nature of the wastes being discussed.

Filter clays

Clays are used for treating a number of products. One use, represented by samples from refineries C-3 and B-4, is the final treating of lubricating oil base stocks to improve color and, if any are present, to remove acidic compounds. This type of operation is being phased out at most lube oil manufacturing operations and being replaced by mild hydrogenation or hydrotreating. The hydrotreating does a better job of improving color, increasing stability against oxidation, has no yield loss (the oil measured in the filter clay represents a loss of some of the most costly products produced in a refinery) and eliminates the problem of disposing of the spent clay. Since the lubricating oils treated with clay have been highly refined (i. e., deasphalted, liquid-liquid extracted and dewaxed) there should be very little material removed by the filter clay. Measured quantities of potentially hazardous materials probably were in the original clay.

Another clay treating operation represented by a sample from refinery A, is fixed bed treating of an aromatic petrochemical extract such as the benzene, toluene, and xylene (BTX) fraction extracted from catalytic reformate. This treatment is used to improve the acid wash color test, and basically, removes any trace olefins or diolefins present in the extract. Eventually, this clay becomes coked or is not sufficiently active to remove olefins and must be dumped from the tower and disposed of. Again, the material being treated has been highly refined (distilled, hydrotreated, reformed, and liquid-liquid extracted) and the only materials removed by the clay are traces of extraction solvent and hydrocarbons. Most of the potentially hazardous materials shown in the analysis were probably present in the original clay.

The clay sample from refinery C-4 was used to give a final treatment to a lubricating oil additive. The clay treating is carried out after a sulphonation operation and removes traces of unreacted sulfuric acid or oleum. Most of the measured materials probably were present in the clay, although some might come into the operation with the

H_2SO_4 or SO_3 used in the sulphonation step.

The clay from refinery A-2 is used to treat kerosene. It appears that this kerosene is treated prior to filtration with a copper-containing compound. The filter clay is then used to remove excess copper carried out with the kerosene. Other potentially hazardous materials were probably present in the fresh clay.

The spent filter clays have high oil adsorption qualities which make them ideally suited for use on in-plant oil spills. These clays are used typically from the filtration of light-end distillates and lube oils. Rather than immediately disposing of this spent clay, the refineries stockpiled them within the diked areas around the refinery until used. Stockpiling of the clay also allows the distillates to evaporate and the hydrocarbons to degrade by microbial action.

Spent clays constitute one of the largest waste streams in several of the Type IV refineries. At least one of these refineries has mentioned that it will attempt to recycle this clay. It is not known what type of process will be used, but previous work on the regeneration of clay by burning the residual oil with air, using oil roasting kilns or similar equipment, has rarely been satisfactory. Close temperature control is necessary for the clay to maintain its activity, and with the variations in the amount of residual oil left on the clay this becomes extremely difficult. The Socony-Mobil Oil Company has developed their Thermofor kiln for the regeneration of non-activated clay. The equipment is rather complex. The process consists of washing the spent clay with naphtha to free it from oil and render it mobile. It is dried by steam heating and fed to the clay burning kiln where it is regenerated by controlled combustion of the absorbed impurities. The unit process is quite complex, and a considerable amount of auxiliary equipment is required. This type of unit process has been in use for many years on a batch basis, but has as yet never been integrated into a continuous process.

Coke fines

In a Delayed Coking Unit, residuum from the fractionation of crude petroleum is heated to a high temperature (880-930 F.) and passed into large drums with a high residence time. The heaviest materials form a layer of coke on the inside of the drums. When the drums are full of coke, the feed is switched to another drum and the coke is removed by high pressure water sprays. The water cuts the coke into fairly large chunks but also produces some fine materials. Some of these fines remain in the water which is usually recycled to the cutting operation. Some of these fines settle out in the water storage vessels and are removed intermittently. Some of the fines remain with the coke and will drop to the ground or pavement during handling of the coke. These fines are also collected and disposed of.

All non-volatile metals contained in the crude petroleum remain in the residues from crude distillation and are concentrated in the coke. These metals are predominately vanadium and nickel along with traces of other elements as shown in the coke fines samples from refineries A and A-6.

Fluid Coking uses the same feed stock, but after heating, it is sprayed onto a flowing mass of fine coke particles. The new coke is formed on the coke particles which are then transferred to a burner (or regenerator) where the new coke is partially burned to provide heat for the reactor. Some of the coke is removed from the system and represents the net coke production. The fluidized coke contains relatively fine particles and includes a much greater proportion of dust or coke fines than in delayed coker coke. As in the case of delayed coking, the coke will contain most of the non-volatile metals from the original crude as shown in the samples from refinery C-1.

A new type of coking unit, called a Flexicoker, is essentially a Fluid Coking Unit with an added gasifier vessel in which the net coke production is gasified with steam and oxygen or air to produce a low to medium BTU fuel gas. It is not possible to gasify all the coke. Some 10-20% of the net production must be removed from the gasifier in order to remove the metals. The removed coke contains all the non-volatile metals from the crude but in an even more concentrated form, as shown by the sample from refinery B-2.

Fluid catalytic cracker (FCC) catalyst fines

The major contaminating metals found on catalytic cracking catalysts are vanadium, nickel, copper, chromium, and iron. Small amounts of these metals are present in the crude petroleum and except for some of the iron, all are in the form of metal-organic compounds. Some of these compounds are volatile and when the vacuum gas oil feed to catalytic cracking units is prepared, they appear in the gas oil. Most of the iron and probably the chromium found on the catalyst is the result of erosion and corrosion either in the lines, equipment, or tanks through which the gas oil passes.

When the feed comes in contact with the catalyst, most of the metal compounds are tightly adsorbed on the catalyst. In the catalytic cracking unit regenerator, where coke is burned off the spent catalyst, the organic portion of these molecules is burned and the metals are oxidized to an inorganic oxide and remain on the catalyst. Corrosion and erosion products may be mixed with the catalyst as fine particles or may also be adsorbed on the catalyst surface.

The heavy metals, vanadium and nickel, and to a lesser extent, iron and copper, act as dehydrogenation catalysts and produce excessive quantities of undesirable coke and light gases (especially hydrogen). In many cases, these metal contaminants are the primary reason for discarding parts of the equilibrium catalyst. Fresh (uncontaminated) catalyst is then added to maintain a reasonable average level of contaminants.

One recent series of analyses* of catalysts from most of the fluid catalytic cracking (FCC) units in the United States showed the following mean concentration values and significant ranges (in mg/kg):

Metal	Mean	Range
Vanadium	445	122 - 1626
Nickel	242	76 - 772
Copper	14	4 - 57

Most of the analyses reported in the analytical program of this study fall within these ranges. The variations between the samples are primarily due to the different crude sources used to prepare the feedstock.

A mild hydrogenation or hydrotreating process is used on the catalytic cracking feed to some units. This feed treatment removes some of the metal compounds and has other good effects on the catalytic cracking operation (i. e. , removing sulfur which reduces the amount of sulfur emissions from the regenerator and in the products, increasing conversion to desirable products such as gasoline, etc.). Among the samples analyzed, the three from refineries C-4, B-2, and B-4 used the hydrotreating process. The hydrotreating step reduces the metal content of the FCC feed, allowing the FCC to operate with less makeup of fresh catalyst. The catalyst used for hydrotreating is usually cobalt and molybdenum on a silica alumina base. The catalysts from both refineries C-4 and B-4 contain larger than normal concentrations of cobalt and molybdenum.

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* Analyses carried out by the Davison Chemical Division, W. R. Grace Co.

It is interesting to note that lead was found as a constituent in the catalyst when analyzed. The only explanation we can offer for this is that possibly some alkyl-lead compounds may find their way into the FCC feed via slop oil reprocessing.

The total weights of catalyst fines produced by the several units sampled varies considerably. The amount of discarded catalyst fines is low for those units which do not have an electrostatic precipitator (refineries B-1, A-5, A-3, A-4 and C-1). A major portion of the fines from these units are lost from the regenerator stack. Those units which do have electrostatic precipitators (a, C-4, C-3, and B-4) produce larger quantities of waste FCC fines which must be disposed of. The one exception to this is refinery C-4 which has a low discard rate, and hence, a higher concentration of metals on the catalyst fines. This may be the result of hydrotreating all of the FCC feed in this refinery.

Neutralized HF alkylation sludge

The two samples collected represent the sludges produced when vent gases produced from hydrofluoric acid (HF) alkylation units are neutralized with the spent lime from boiler feedwater treatment. Both sludges contain appreciable quantities of fluorides, however, they are probably entirely in the insoluble calcium fluoride form as indicated by the high pH (12.9 and 9.5) of the aqueous fraction of the sludge. Other potentially hazardous materials in these sludges probably were present in the fresh HF or lime, or in the water prior to its treatment.

Cooling tower sludge

The analytical results for all constituents shown would appear to be in a range that one could reasonably expect with the exception of cyanide from refinery C-4 and selenium from refinery A. The concentration of cyanide of 17.2 mg/kg is high for this service, most likely the result of a leak from the process into the cooling water system. Selenium at a level of 24 mg/kg is also high. Unless the selenium is present as an impurity in the treating chemicals, it cannot be accounted for.

Slop oil emulsion solids

The analytical results for this waste appear reasonable except in a few instances. At refinery A-1, the concentration of cyanide (54.4 mg/kg) is either an error or a large leak from the cracking unit and should be discounted. In addition, chromium from refinery A-6 at 1.0 ppm is unusually low even for a refinery using non-chromate water treatment.

Once-through cooling water sludge

All results appear reasonable except for the concentration of selenium at refinery A-5. A level of 10.4 ppm indicates an unusual degree of contamination in the silt for once-through cooling water.

Spent lime from boiler feedwater treatment

All results appear reasonable except for the concentration of selenium at refinery A-4. This high value is possibly present in boiler feedwater treatment chemicals. This refinery is also recycling its wastewater, which may account for the high quantities of arsenic, mercury, vanadium, chromium, copper, and zinc that appear. However, these contaminants may also be present in the boiler feedwater treatment chemicals.

Exchanger bundle cleaning sludge

All results appear reasonable. The level depends on the service of the exchangers that were cleaned.

API separator sludge

All results appear reasonable except for the sample taken at refinery A-3 where the constituent levels are high because the sludge has been centrifuged. If the values are normalized by adding oil and water in the same proportion found in other sludges, the numbers will reduce to that which might normally be expected. Chromium and zinc concentrations for this sample are very low due to the non-chromate water treatment. This type of treatment is not typical.

Dissolved air flotation (DAF) float

All numbers appear reasonable except for the lead concentration at refinery B-4. A level of 1250 mg/kg is either an analytic error or the result of a plant spill/leak. This is approximately the concentration of lead in gasoline, and in any case is not typical.

Leaded tank bottoms

All results appear reasonable except for a few instances. The phenol concentration at refinery C-4 appears to be very high since most phenols are eliminated by hydrotreating.

Arsenic levels in the leaded tank bottoms at refineries C-4 and B-2 are also high. Arsenic in gasoline is normally present only at levels of 1 mg/kg or less with the arsenic usually removed by hydrotreating. Possibly, the arsenic is a contaminant of the gasoline additives.

Zinc in the samples from refineries C-4 and B-2 for leaded tank bottoms is also present in unusually high quantities. Possibly, this might be the precipitated product of brass corrosion (dezincification) in exchangers. If so, this should be verified since brass is no longer commonly used. The zinc quantity is not typical.

Crude tank bottoms

All results appear reasonable except for the concentration of lead from refinery B-4. This cannot be accounted for unless the refinery is recycling their slop oil to the crude tank.

In reviewing all refinery B-4 waste streams, a number of them seem to have excessively high lead contents. It is possible that this is a uniquely high lead-bearing crude.

Non-leaded tank bottoms

All constituent levels appear reasonable except for the concentration of copper and zinc from refinery C-4, which cannot be explained. If this is the result of product additives, then it is typical only of a specific sludge.

APPENDIX J

FACTORS UTILIZED IN EXTRAPOLATING REFINERY WASTE QUANTITIES FOR 1974*

Waste	Factor Based on Utilization	Factor Based on Cleaning Frequency
Waste bio sludge	From the Clean Water Report (1), 90% of the refineries have a secondary biological system in 1974	None
Storm water silt	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 25% of all refineries have a separate storm water sewer system which would collect silt	None
Spent lime from Boiler feedwater treatment	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 75% of refineries employ lime softening to treat boiler feedwater	None
Kerosene filter clays	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 30% of the refineries generate waste filter clays from treating kerosene products	None
Non-leaded tank bottoms	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries generate this waste	Once every 10 years

(*) References for Appendix J: p. 289

1974

Waste	Factor Based on Utilization	Factor Based on Cleaning Frequency
API separator sludge	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries generate this or an equivalent waste	None
Leaded tank bottoms	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries generate this waste	Once every 6.5 years
Cooling tower sludge	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 25% of the refineries generate this waste as a separate source	None
Crude tank bottoms	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 75% of all refineries generate this waste--the remaining utilize mixers which eliminate this waste	Once every 3 years
Dissolved air flotation (DAF) float	From the Clean Water Report (1), 20% of the refineries utilize some form of dissolved air flotation	None
Exchanger bundle cleaning sludge	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 10% of all refineries generate this waste or an equivalent as a separate source	None

1974

Waste	Factor Based on Utilization	Factor Based on Cleaning Frequency
Slop oil emulsion solids	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries generate this waste	None
Once-through cooling water sludge	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 15% of the refineries generate this waste	None
Lube oil filter clays	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries producing lubes generate this waste	None
Fluid catalytic cracker (FCC) catalyst fines	From field visits and Jacobs Engineering in-house knowledge, it is estimated that 100% of the refineries having an FCC unit generate this waste	None
Coke fines	From field visits and Jacobs Engineering in-house knowledge, it is estimated that all refineries producing coke generate this waste	None
Neutralized HF alkylation sludge	From field visits and Jacobs Engineering in-house knowledge, it is estimated that all refineries having an HF alkylation unit generate this waste	None

FACTORS UTILIZED IN PROJECTING WASTE QUANTITIES FOR 1977*

(Expected changes from 1974)

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Waste bio sludge	From information supplied by the API Solid Waste Task Force, all refineries should have some form of secondary biological treatment	No change	Due to environmental requirements, it is estimated that the amount of Cr and Zn should decrease by 17%	None
Storm water silt	Due to more refineries installing segregated sewer systems, it is estimated that 10% more refineries will generate this waste	No change	No change	None
Spent lime from boiler feedwater treatment	Due to more refineries turning to this form of boiler water treatment, it is estimated that 5% more refineries will generate this waste	No change	No change	None
Kerosene filter clays	It is estimated that the use of clay filters will decrease by 17% due to the use of other forms of kerosene treating	No change	No change	None

(*) Increases in various unit capacities are not included. However, increases in production were taken into account using Table 33.

1977

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Non-leaded tank bottoms	No change	No change	No change	None
API separator sludge	No change	No change	Due to environmental requirements, it is estimated that the quantities of Cr and Zn will be reduced by 17%	None
Crude tank bottoms	No change	Due to an increase in mixers and extracting oil from the tank sludge, this waste should decrease by 10%	No change	None
Dissolved air flotation (DAF) float	From the Clean Water Report (1) the utilization of this unit will increase by 50%	No change	Due to environmental requirements, it is estimated that Cr and Zn will be reduced by 17%	None
Leaded tank bottoms	No change	Due to a reduction in the use of leaded gasoline, it is estimated that the quantity of this waste will decrease by 17%	Due to a decrease in the lead content of gasoline, the lead concentration will decrease by 25%	None

1977

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Cooling tower sludge	Due to an increase in air cooling, this sludge will be decreased by 10%	Due to an increase in air cooling and better cooling tower design, the quantity will decrease by 10%	Due to environmental requirements, the Cr and Zn concentration will decrease by 17%	None
Exchanger bundle cleaning sludge	No change	No change	No change	None
Slop oil emulsion solids	No change	Due to an increase in oil recovery, this waste will decrease by 17%	Due to environmental requirements, the Cr and Zn concentrations will decrease by 17%	None
Once-through cooling water sludge	Due to a decrease in the number of refineries employing once-through cooling water, utilization will decrease by 66.7%	Due to environmental requirements, i.e., stricter limitations on return of once-through CW back into a river, the waste quantity will increase by 10%	No change	None
Lube oil filter clays	No change	No change	No change	None

1977

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Fluid catalytic cracker (FCC) catalyst fines	No change	Due to an increase in the use of electrostatic precipitators or equivalent, the waste will increase by 75%	No change	None
Coke fines	No change	No change	No change	None
Neutralized HF alkylation sludge	No change	No change	No change	None

FACTORS UTILIZED IN PROJECTING WASTE QUANTITIES FOR 1983*

(Expected changes from 1977)

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Waste bio sludge	No change	No change	Due to environmental requirements, it is estimated that Cr and Zn will decrease in concentration by 40%	None
Storm water silt	Due to an increase in the number of refineries employing segregated sewer systems, the utilization will increase by 20%	No change	No change	None
Spent lime from boiler feedwater treatment	Due to an increase in the number of refineries using this method for water treatment 10% increase in utilization is expected	No change	No change	None
Kerosene filter clays	Due to more refineries employing alternate methods for treating kerosene, the utilization factor will decrease by 40%	No change	No change	None

(*) Increases in various unit capacities are not included. However, increases in production were taken into account using Table 33.

1983

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Non-leaded tank bottoms	No change	No change	No change	None
Crude tank bottoms	No change	Due to an increase in mixers and extracting oil from the tank sludge, the waste should decrease by 25%	No change	None
API separator sludge	No change	No change	Due to environmental requirements, Cr and Zn will decrease in concentration by 40%	None
Dissolved air flotation (DAF) float	From the Clean Water Report (1) the utilization of this unit will increase by 33.3%	No change	Due to environmental requirements, it is estimated that Cr and Zn will be reduced by 40%	None
Leaded tank bottoms	No change	Due to a reduction in the use of leaded gasoline, it is estimated that the quantity of this waste will decrease by 40%	Due to a decrease in the lead content of gasoline, the lead concentration will decrease by 30%	None

1983

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Cooling tower sludge	Due to an increase in air cooling, this waste will decrease by 20%	Due to an increase in air cooling and better cooling tower design, the quantity will decrease 15%	Due to environmental requirements, Zn and Cr will decrease in concentration by 40%	None
Exchanger bundle cleaning sludge	No change	No change	No change	None
Once-through cooling water sludge	Due to a decrease in the number of refineries employing once-through cooling water, utilization will decrease by 60%	Due to environmental requirements, i.e., stricter limitations on return of once-through CW back into a river, the waste quantity will increase by 10%	No change	None
Lube oil filter clays	No change	No change	No change	None
Fluid catalytic cracker (FCC) catalyst fines	No change	No change	No change	None

1983

Waste	Factors Based on Utilization	Inherent Process Efficiency or Management May Change Quantity of Waste Per Unit of Capacity	Factors Based on Change in Concentration	Factors Based on Cleaning Frequency
Coke fines	No change	No change	No change	None
Neutralized HF alkylation sludge	No change	No change	No change	None

References:

(1) The Cost of Clean Water, Volume III, Federal Water Pollution Control Administration, 1967.

APPENDIX K*

TWO PROCEDURES FOR THE DISPOSAL OF LEADED-GASOLINE SLUDGE FROM GASOLINE PRODUCT STORAGE TANKS

Two basic procedures for the disposal of leaded-gasoline sludge from gasoline product storage tanks were developed and disseminated to the refineries by the Ethyl Corporation (1, 2) and duPont. The older procedure involves the construction of a large, shallow dike around the gasoline product storage tank which is to be cleaned. The excavated material is placed around the periphery of the dike to make a berm. The tank is opened, and the contents, down to the sludge layer, pumped to another storage tank. The leaded-gasoline sludge is pumped into the dike, where in the presence of sunlight and air, it rapidly evaporates and weathers.

After a suitable period of time, which is largely dependent on the climate, the contents of the dike are covered with the surrounding soil. A modification of this procedure is relocation of the material elsewhere on the refinery property for burial. Many of the refineries had completely fenced and locked areas of land set aside exclusively for the burial of leaded-gasoline sludge. Only one of the refineries contacted disposed of this material in an off-site municipal sanitary landfill.

The observation that leaded-gasoline sludge which had been buried for many years still indicated potentially-toxic levels of tetraethyl lead resulted in the development of an alternate procedure for its disposal. Using the new procedure, the leaded gasoline sludge is (a) pumped from the storage tanks onto the ground in the diked area in which the storage tank is located, or (b) is transported to a weathering pad elsewhere within the refinery. The material is spread in layers, two to four inches thick, and allowed to weather and evaporate for a period of at least four weeks. In some northern climates, as much as four months may be required for this weathering. The leaded-gasoline sludge is sampled at regular, periodic intervals to determine the tetraethyl lead concentration. After the concentration falls to a level of below 20 parts per million, which is considered a safe level, the material is either thinned and rotodisked into the soil in the tank dike area or scooped up and buried somewhere on the refinery property.

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*References for Appendix K: p. 291

A technical communication from the Ethyl Corporation(*) pointed out that degradation of buried sludge is very slow and probably not complete. They suggest that the sludge be spread on the soil surface and be allowed to weather for an indefinite period of time, if possible. This allows greater evaporation of volatile fractions and greater weathering in the presence of sunlight and air.

References (Appendix K):

1. Procedures for disposal of sludge from leaded gasoline storage tanks from Section 6 of Ethyl Corp. Tank Cleaning Manual.
2. Ball, H. D. Methods of disposing of sludge from leaded gasoline storage tanks. An Ethyl Corp. publication.

(*) Source: K. C. Jost, Manager Product Service and Safety, Ethyl Corp., January 1975.

APPENDIX L

A DESCRIPTION OF THE CHEMFIX PROCESS

(For the chemical fixation and solidification of complex waste
mixtures to be used as landfill)

The Chemfix process utilizes a two-part, inorganic chemical system which reacts with all polyvalent metal ions and with certain other waste components; it also reacts within itself to form a chemically and mechanically stable solid. This system, now patented, is based on the reactions between soluble silicates and silicate setting agents which react in a controlled manner to produce a solid matrix. The matrix itself, as produced, is actually a pseudo-mineral. It is based on tetrahedrally coordinated silicon atoms alternating with oxygen atoms along the backbone of a linear chain. The charged side groups - in this case oxygen - in reaction with polyvalent metal ions result in strong ionic bonding between adjacent chains to form a cross-linked, three-dimensional, polymer matrix which is very much like many of the natural pyroxene minerals. This type of structure displays properties of high stability, high melting point, and a rigid, friable structure, very similar to many soils.

Three classes of interactions take place in such a system. First are the very rapid reactions between soluble silicates and nearly all polyvalent metal ions, producing very insoluble metal silicates. These insoluble compounds are non-toxic and cannot easily be resolubilized later on. In some cases, of course, they are similar to the minerals from which the metals were originally extracted, and it is claimed that they are quite resistant to breakdown under environmental conditions.

The second set of reactions occurs between the soluble silicate and reactive components of the setting agent. The setting agent is usually so formulated or chosen that the cross-linking ions have limited solubility but a high reserve capacity, allowing the reaction to take place slowly under controlled conditions. (This is analogous to buffering capacity in acid-base reactions.) In addition to operational requirements which are served by such controlled reaction rates, the gel structure which is thus formed is more suitable to producing good solid properties, especially in waste which has a high water content. The gel acts as a sort of sponge and has the unique property of being able to hold very large quantities of water while acting in all respects like a solid. The gel reaction can occur quickly enough, for example, in seconds or minutes, to prevent the settling out of solids which one wants to contain in the structure. Because of its properties, the gel holds ions in place by various chemical and physical bonding mechanisms and thereby acts much as an ion exchange resin. Other waste components such as oils are also entrapped in the structure and thereby immobilized. The third class of reactions (depending upon the setting agent used) occurs between the setting agent and the waste and/or water, as it undergoes a series of hydrolysis, hydration and neutralization reactions.

A typical operating unit consists of a mobile van 40' long and 8' wide, which contains the chemical storage, metering and mixing equipment to operate the process at flow rates of 300 to 500 gpm. The process is continuous and occurs at ambient temperature and pressure. Process control is maintained by automatic equipment which meters the required ratios of chemical reactants into the waste as it flows through the unit.

APPENDIX M

EXAMPLES OF REFINERY WASTE GENERATION RATES: A RECORD OF DISPOSAL OF FOUR CALIFORNIA REFINERIES BETWEEN 1968 and 1973

Wastes that need disposal to a landfilling operation may be produced continuously within the refinery, however disposal is a discontinuous process dependent upon a number of variables. These variables include size of the equipment storing the sludges, seasonal demands, process changes, etc. The attached data represent a record of waste disposal of four refineries in the Los Angeles area between the years 1968 and 1973. This record is presented to indicate the variability in disposal practices, and not necessarily as typical examples. The data presented in Section 4.0 should be interpreted against this background. All quantities are given in barrels unless otherwise indicated.

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APPENDIX M

A RECORD OF WASTE DISPOSAL BY REFINERY A
(AS REPORTED TO LOS ANGELES COUNTY ENGINEERS DEPARTMENT)
(all quantities in barrels unless noted)

Monthly Totals for 1968

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
TCL				1,200					600	1,700	2,000	
Palos Verdes						400				1,400	1,000 + 24 tons	
Sludge												
Palos Verdes							800					
TCL							100					
Lime - soda ash sludge												
Palos Verdes							600			100		
Non-oily												
Palos Verdes						900						
TCL						100						
Polymer												
Calabasas									900			
Palos Verdes											200	
Spent acid												
Sea						1,100	1,400					
Palos Verdes							13			1,200		
TCL										300		

Monthly Totals for 1968 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Caustic (Cresylic Acid & Phenols)												
Basin by products dump									2,800			
Palos Verdes						200			100		900	
Puente waste disposal									500		165	
ASCON											165	
TCL										600		
TOTALS				1,200		2,700	2,913		4,900	5,300	4,430 + 24 tons	

Monthly Totals for 1969 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
Palos Verdes	100				800			100				400
La Puente					100							
TCL					3,000			1,900	1,500			590
BKK												100
Sludge												
Palos Verdes	48											150
TCL												450
Lime - soda ash sludge												
TCL									1,200			
PV									250			
La Puente									150			
Sea												700
Non-oily												
TCL					550							
Polymer												
Calabasas		686	200									600
Palos Verdes	100										800	1,000

Monthly Totals for 1969 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Spent acid												
Palos Verdes	400		424									
TCL						50						
Riverside						100						
Caustic												
TCL												200
BKK												100
Catalyst												
TCL						100		300				200
PV						100						
Lampblack												
(Unidentified)								50				
Slop oil												
Palos Verdes												2,450
TCL												100
TOTALS	648	686	624		4,450	350		2,350	3,100		800	7,040

Monthly Totals for 1970 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
Palos Verdes					500							
BKK			600	900	250							
Loganita					500							
TCL	200											
Slop oil												
TCL					150							
BKK-La Puente	1,000	1,400	5,400	1,200	4,650							
Palos Verdes	2,000	900	1,750	750	2,800							
Loganita					4,200							
Oily water												
TCL	400											
Norwalk	100											
BKK-La Puente			250		1,000							
Palos Verdes	100		170	200	900							
ASCON				300	300							
B.I. catalyst sludge												
Palos Verdes			100									
BKK-La Puente			500									
Waste polymer												
Calabasas			100									
Palos Verdes	600	400	400		900							

Monthly Totals for 1970 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Filter clay												
TCL		250										
Palos Verdes		300										
Spent acid (HCL)												
BKK		200	1,300		150							
Spent soda sludge												
Sea	100											
Palos Verdes	200											
TCL	200											
BKK-La Puente	100	1,800	200		200							
Aqueous sludge												
BKK-La Puente			100									
Sour water												
BKK-La Puente	50											
Brine solutions												
TCL	50											
Waste solvent												
Palos Verdes			200									

Monthly Totals for 1971 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
BKK					200					150		
Palos Verdes					100				1,000	250		
ASCON					50	50			200	100		
Slop oil												
ASCON								100				
Loganita		50										
Palos Verdes					100		100	800		100		
Oily sludge												
Calabasas		114								210		
PV		1,850			50	50				2,500		
BKK					200					2,400		
Loganita						50						
Oily water												
BKK		200										
Palos Verdes		400			50				100	100		
ASCON							50	100				
Spent acid (H_2SO_4)												
BKK									100			
Basin by-products dump							200					

Monthly Totals for 1971 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Spent soda												
Palos Verdes		100			100		700	100				
BKK							100	100		300		
Loganita										100		
Cresylic sludge												
BKK										200		
Dilute aqueous cresylic acid												
BKK					300							
ASCON					100							
Loganita					100							
SBA polymer												
Palos Verdes						240	960	240				
Calabasas		440										
Cal Salvage						100	200					
BKK		110										
Acidic waste polymer												
Calabasas					120	240						
Palos Verdes		156										

Monthly Totals for 1971 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Aqueous sludge												
BKK		600										
Palos Verdes		100				744	710	330				
Calabasas					962	744						
Cal Salvage						220						
B.I. catalyst sludge												
BKK									200			
PV									100			
Coke sludge												
Palos Verdes										200		
BKK										100		
TOTALS		4,120			2,432	2,438	3,020	1,770	1,700	6,710		

Monthly Totals for 1972 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
Palos Verdes									110	214	520	210
BKK									150		100	300
Bryant							1,430		3,769			
ASCON							3,600					
Cal Salvage							110		150		110	
Simi										500	400	
Oily water												
Palos Verdes							550				1,750	
BKK							200				1,300	
Simi							100				300	
Bryant									110			
Aqueous sludge												
Palos Verdes							110					
Desalter sludge												
Palos Verdes							1,800					
Foamite sludge												
Palos Verdes							1,500					
Loganita							600					

Monthly Totals for 1972 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Coke sludge												
Palos Verdes							700				200	100
BKK							200				100	
Bryant							300					
Simi							200					
Alkaline charcoal												
Palos Verdes							300					
ASCON							100					
B.I. cat. sludge												
Palos Verdes						200						
Spent soda sludge												
Palos Verdes							500					
(Wilmington) Elanby dump											50	
Filter clay												
Palos Verdes										100	100	
BKK											100	
FCC fines												
BKK												100

Monthly Totals for 1973 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Oil & mud												
Palos Verdes	210		200	2,994		2,540	550					
Cal Salvage				110		50						
BKK				2,100		1,360						
Calabasas			110									
Agoura				1,700								
Bryant		330	300	1,700								
Slop oil												
Basin by-products	100											
Palos Verdes						380						
Oily water												
Bryant			230									
Palos Verdes			200									
Sand and water												
Palos Verdes			300									
Filter clay												
Palos Verdes			200	650	400							
ASCON				100								
BKK		200										

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Monthly Totals for 1973 (Refinery A)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Spent acid (H_2SO_4)												
Palos Verdes						200						
Aqueous sludge												
Cal Salvage		110			100							
FCC fines												
Palos Verdes			800	100	444							
BKK			600									

APPENDIX M (continued)

A RECORD OF WASTE DISPOSAL BY REFINERY B
(AS REPORTED TO LOS ANGELES COUNTY ENGINEERS DEPARTMENT)

(all quantities in barrels unless noted)

TYPE OF WASTE AND DISPOSAL LOCATION	Monthly totals for 1968											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes				6,300	6,600		7,250	3,800	4,200	2,000	15,350	12,500
La Puente				6,600	200		200	300			8,700	200
TCL				100	4,400		1,550	700	100	100		
Main Street					900							
Norwalk					600							
Monterey Park									600	12,900		
Huntington Beach												2,800
Total				13,000	12,700		9,000	4,800	4,900	15,000	24,050	15,500
Non-oily												
TCL				1,393								
Mud slurry												
TCL				250	500		1,275	1,175	2,550	2,500	1,050	1,300
Spent lime												
TCL				1,725	1,500		100	300			2,100	1,050
Liquid wax												
Palos Verdes											100	
Catalyst slurry												
TCL							100					
TOTAL				16,368	14,700		10,475	6,275	7,450	17,500	27,300	17,850

Monthly Totals for 1969 (Refinery B)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes	1,900	9,500	10,100	1,600	2,600		3,800	900	500			
La Puente		200	200									
Calabasas		200										
BKK		400										
TCL		800										
PODCO		400	700	1,200	1,350		600					
Total	1,900	11,500	11,000	2,800	3,950		4,400	900	500			
Mud slurry												
TCL	1,600	2,350	1,750	1,750	1,700		1,650	4,050	3,200			
Spent lime												
TCL			250	400			900	1,000	650			
Catalyst												
TCL			50				200					
TOTAL	3,500	13,850	13,050	4,950	5,650		7,150	5,950	4,350			

Monthly Totals for 1970 (Refinery B)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes		13,331	7,600	3,041	11,448		3,700	1,100	8,700			
TCL		300										
ASCON									800			
BKK					50		100	50				
Loganita					3,800		700					
H&D Maintenance							3,700	16,300	6,300			
Paramount salvage									13,400			
Non-oily												
Palos Verdes				230								
ASCON			500			500						
BKK			100									
Spent acid												
BKK				300								
Spent lime												
ASCON		200	1,000	1,700	2,050	2,200	1,750	2,300	2,900			
TCL		1,292										
BKK									200			
Sludge												
Palos Verdes			200									
BKK			200									
ASCON									100			

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Monthly Totals for 1970 (Refinery B)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Wash water												
Palos Verdes			114									
FCC catalyst fines (lbs.)*												
ASCON		216,670	300,675	221,440	249,640	387,580**	334,680	391,400				

*Dry FCC catalyst fines removed by electrostatic precipitator, 40.58 lbs/ft^3

**Dry FCC catalyst fines removed by electrostatic precipitator, 47.4 lbs/ft^3

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Monthly totals for 1971 (Refinery B)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes			300			7,500	10,700	3,400	500			
Calabasas									200			
BKK									900			
Slop oil												
Palos Verdes									200			
BKK									100			
Spent lime												
Palos Verdes								1,900				
ASCON			1,800			2,700	1,900					
Total			2,100			10,200	12,600	5,300	1,900			
FCC catalyst fines (lbs.)*												
ASCON			171,160			278,560	248,140	377,700				

*Dry FCC catalyst fines removed by electrostatic precipitator, 40.58 lbs/ft^3.

TYPE OF WASTE AND DISPOSAL LOCATION	Monthly Totals for 1972 (Refinery B)											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes												2,400
BKK										400		
SMMI								31,300	17,300	5,500		2,750
Bryant									2,500	100		
Spent lime												
ASCON								2,600	3,100	1,700	2,600	2,100
FCC catalyst fines (lbs.)*												
Palos Verdes								295,140	174,520	294,880	253,280	269,300

*Dry FCC catalyst fines removed by electrostatic precipitator, 40.58 lbs/ft^3.

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Monthly Totals for 1973 (Refinery B)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Oily wastes												
Palos Verdes				320	1,900	1,243						
BKK						10,300						
SMMI		1,700										
Bryant			800	3,500								
Spent lime												
Palos Verdes				2,200								
ASCON		2,200	2,700		2,200	2,400						
FCC catalyst fines (lbs.)*												
Palos Verdes		266,660	238,180	45,300	583,120	256,000						

*Dry FCC catalyst fines removed by electrostatic precipitator, 40.58 lbs/ft^3.

APPENDIX M (continued)

A RECORD OF WASTE DISPOSAL BY REFINERY C
(AS REPORTED TO LOS ANGELES COUNTY ENGINEERS DEPARTMENT)

(all quantities in barrels unless noted)

Monthly Totals for 1971 (Refinery C)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
Miscellaneous non-recoverable oil mixes												
Palos Verdes	4,760	835		700	320		450	9,270	300	3,418	4,635	800
ASCON	1,950	2,950		485	500		50		100			
H&D Dump (Wilmington)	50	5,300					400					
Loganita (Terminal Island)		2,600										
Tank bottoms												
Palos Verdes	540								255	450		
ASCON (Wilmington)	555											
H&D	1,110											
Mud slurry												
Palos Verdes	700	1,250		3,000	750		1,100	1,800	568	2,300		
BKK					50							
ASCON	2,000	5,150		4,850	6,700		8,785	8,168	2,250	3,450	6,505	5,305
Cal Salvage (San Pedro)											700	

Monthly Totals for 1971 (Refinery C)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
J.K. Bryant - Carson H&D dump	100	100		400							100	
Spent acid BKK									5			
Brine ASCON							550		200			
	11,765	18,185		9,435	8,320		11,335	19,238	3,678	9,618	11,940	6,105

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Monthly totals for 1972 (Refinery C)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Miscellaneous non-recoverable oil mixes												
Palos Verdes	5,918	3,855	1,346	1,200		3,718	1,918	10,104	12,936	1,614	1,036	3,868
SMMI							1,000	450	200	118	100	
J K Bryant (Garden Grove)									1,500			
Mud slurry												
Palos Verdes							320		150	2,552	3,194	3,122
SMMI							800			100		
ASCON	9,153	6,369	6,386	3,418		2,900						
Dilute acid												
L A Co						75						

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Monthly totals for 1973 (Refinery C)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
Miscellaneous non-recoverable oil mixes												
Palos Verdes	50			300			500					4,968
BKK			100		100							
Mud slurry												
Palos Verdes	5,326	1,948	7,292	10,000	11,914	4,574	2,546	9,839	15,536	10,424	8,704	8,974
BKK	268	1,640	1,322	120		68		580	400	368	568	1,268
J K Bryant (Seal Beach)		310	520	520								
Cal Salvage			310				100	25				
SMMI		1,336										
ASCON							150	525				
Baker Quantity (Signal Hill)							100					
Dilute caustic												
BKK					100							
Dilute acid												
Basin By-Products Co, Long Beach				65								
Palos Verdes							2					

APPENDIX M (continued)

A RECORD OF WASTE DISPOSAL OF REFINERY D
(AS REPORTED TO LOS ANGELES COUNTY ENGINEERS DEPARTMENT)
(all quantities in barrels unless noted)

MONTHLY TOTALS FOR 1969 (Refinery D)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVE/MO.
Liquid wastes (BBLS)													
Palos Verdes					10,300	4,300	2,600	700	1,500	900	1,400	1,500	
BKK						5,800	6,900	4,000	1,500	2,100	100	1,500	
Totals					10,300	10,100	9,500	4,700	3,000	3,000	1,500	3,000	5,638
Solid wastes (YD^3)													
Palos Verdes									3,308	14,884			
BKK									22,377	12,960			
Totals									25,685	27,844			
MONTHLY TOTALS FOR 1970													
Liquid wastes (BBLS)													
Palos Verdes	2,900	1,400	3,000	11,600	4,400	10,600	9,350	3,800	2,600	2,235	700	1,300	
BKK	3,100	600	5,100	21,600	4,600	10,200	4,900	3,300	1,200	2,350	550	1,100	
Totals	6,000	2,000	8,100	33,200	9,000	20,800	14,250	7,100	3,800	4,585	1,250	2,400	9,374
Solid wastes (YDS)													
BKK				8,232									
Palos Verdes													
BKK													

MONTHLY TOTALS FOR 1971 (Refinery D)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVE/MO.
Liquid wastes (BBLS)													
Palos Verdes	2,400	400	3,700	4,800	2,400	9,800	6,200	7,000	7,100	7,510	5,435	6,600	
BKK	500	350	1,500	1,100	1,200	2,100	3,400	1,800	2,400	2,250	1,300	1,000	
Bradley											1,800	150	
Totals	2,900	750	5,200	5,900	3,600	11,900	9,600	8,800	9,500	9,760	8,535	7,750	7,016

MONTHLY TOTALS FOR 1972

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVE/MO.
Liquid wastes (BBLS)													
Palos Verdes	7,000	5,900	9,150		4,800	8,100	8,100	7,000	12,537	8,370	3,100	3,950	
BKK	1,500	1,000	1,500		500	2,400	2,600	1,300	2,560	2,000	2,500	2,600	
ASCON					150	3,250							
Cherokee					100								
SMMI								100					
Totals	8,500	6,900	10,650		5,550	13,750	10,700	8,400	15,097	10,370	5,600	6,550	8,506

MONTHLY TOTALS FOR 1973 (Refinery D)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVE/MO.
Tank bottoms													
Palos Verdes		1,200	3,700	4,600	6,300	5,800	6,200	12,900	5,800	6,100	7,000	4,900	
BKK		2,300	2,200	600	700	700	100	2,880	915	2,600	1,200	550	
ASCON										700	200	200	
		3,500	5,900	5,200	7,000	6,500	6,300	15,780	6,715	9,400	8,400	5,650	6,695
Mud slurry													
Palos Verdes				300	2,800	900	550	1,700	800				
BKK		135	1,500	2,300	2,600	1,800	600	1,800	1,600			1,200	
ASCON			200	700	200	800	300	300					
		135	1,700	3,300	5,600	3,500	1,450	3,800	2,400			1,200	2,565
Coke sludge													
BKK					400								
ASCON			100	2,900			200					200	
Drains													
Palos Verdes											700		
BKK											3,000		
ASCON											700		
											4,400		
Catalyst fines													
Palos Verdes										100			

Monthly Totals for 1973 (Refinery D)

TYPE OF WASTE AND DISPOSAL LOCATION	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	AVE/MO.
Spent lime													
Palos Verdes BKK												300 500	
Oil field brine													
Palos Verdes				100									
Oil spreading on property											50		
Totals		3,635	7,700	11,500	13,000	10,000	7,950	19,580	9,115	9,500	12,850	7,850	10,244

APPENDIX N

PARTIAL LIST OF PRIVATE WASTE HAULING AND DISPOSAL CONTRACTORS HANDLING PETROLEUM REFINERY WASTES

ARKANSAS

Pollution Control, Inc.
American Oil Rd.
Little Rock

CALIFORNIA

All American Oil Co.
8655 S. Main St.
Los Angeles 90003

Angelus Pumping Co.
2453 E. 25th St.
Los Angeles 90058

Argo Petroleum Corp.
10880 Wilshire Blvd.
Los Angeles 90024

Atlantic Richfield Co.
515 S. Flower St.
Los Angeles 90071

B & H Vacuum Pump Service
16260 Placid Dr.
Whittier 90604

Barnett Trucking, Inc.
P.O. Box 416
Fillmore 93015

J. S. Brower & Assoc., Inc.
2040 N. Towne Ave.
Pomona 91767

Browning Ferris Industry,
Chemical Services Div.
P. O. Box 44
Wilmington 90744

Capri Pumping Service
3128 Whittier Blvd.
Los Angeles 90023

Julian Galindo Carrasco, Inc.
6959-1/2 E. Olympic Blvd.
Los Angeles 90022

Carrasco Vacuum Truck Service
P. O. Box 1043
Wilmington 90744

Geo. F. Casey Pumping Co.
10052 Miller Way
South Gate 90280

Geo. F. Casey Pumping Co.
21801 Barton Rd.
Colton 92324

Chancellor and Ogden, Inc.
3031 East "I" St.
Wilmington 90744

Chemical Disposal Co.
1138 Princeton, Suite C
Santa Monica 90403

City of Industry Disposal Co.
420 N. Del Valle St.
City of Industry 91744

Crosby and Overton, Inc.
1620 W. 16th St.
Long Beach 90813

D & J Transportation Corp.
15728 Garfield
Paramount 90723

Ecology Control, Inc.
215 E. Rocklite Road
Ventura 93001

Oscar E. Erickson, Inc.
249 Tewksbury Avenue
Richmond 94801

Falcon Disposal Service
3031 E. "I" Street
Wilmington 90744

Federal Prison Industrial, Inc.
Terminal Island
San Pedro 90731

Findly Chemical Disposal, Inc.
12192 Morrie Lane
Garden Grove 92640

Fix & Brain Vacuum Truck
Service
233 East "D" Street
Wilmington 90744

Getty Oil Co.
133 West Santa Clara Street
Ventura 93001

W. E. Gilliard Vacuum Tank
Service
P. O. Box 584
Torrance 90508

H & S Vacuum Trucking
Service
P. O. Box 401
Wilmington 90744

Hapco Co.
13724 Chadron Avenue
Hawthorne 90250

Holbrook & Son Trucking,
Oil Field and Vacuum
12637 Los Nietos Road
Santa Fe Springs 90670

Humble Oil and Refining Co.
2755 Orange Avenue
Long Beach 90807

W. H. Hutchison & Sons
Service Co., Inc.
P. O. Box 3202
Olympic Station
Beverly Hills 90212

Industrial Tank Inc. of
Martinez
Martinez*

Ray E. Karns Co.
3006 San Emidio
Bakersfield 93304

King Pumping Co.
7436 1/2 Laura Street
Downey 90241

Kyle O. Mayes Co., Inc.
800 West 15th Street
Long Beach 90806

Maymanian Disposal Co.
3420 E. Olympic Boulevard
Los Angeles 90023

Arch T. McCoy
4657 Glen Arden
Covina

Mobil Oil Corp.
612 S. Flower St. Rm. 551
Los Angeles 90017

Robert H. Morrison
1176 East 25th Street
Signal Hill 90806

John Preston Nash
101 W. Fremont Square
Montebello 90640

Newhall Refining Co., Inc.
22674 Clampitt Road
Newhall 91321

M. C. Nottingham Co,
Southwest
2926 West First Street
Santa Ana 92703

M. C. Nottingham Co. of
Southern California
4928 N. Walnut Grove Ave.
San Gabriel 91778

Oil and Solvent Process Co.
P. O. Box 907
Azusa 91702

Oil Fields Trucking Co.
1601 South Union Avenue
Bakersfield 93307

Ott's Vacuum Truck Service
1430 East Bastanchury Road
Fullerton 92635

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*Industrial Tank, Inc. of Martinez is the major hauler of petroleum refinery waste materials in the San Francisco area. They handle approximately 80% of all the solid wastes generated by the six petroleum refineries in the area. Industrial Tank operates four Class I sanitary landfills in the area located in San Jose, Martinez and environs, and a fifth site is proposed at Antioch. The remaining 20% of the material hauled from the refineries is handled by another firm which disposes of the material at one of Industrial Tank's Martinez facilities.

Randy's Pumping Service
2402 Troy Avenue
South El Monte 91773

Roberts Liquid Disposal
14708 Studebaker Road
Norwalk 90650

Routh Transportation
800 W. 15th Street
Long Beach 90813

Rubbish Haulers, Inc.
8520 Fishman Road
Pico Rivera 90660

Rich Sand Service Co.
P. O. Box 2403
Orcutt 93454

Shell Oil Co. - West Coast
E & P Division
1008 W. Sixth Street
Los Angeles 90017

Soupy's Pumping Service
3409 Santa Ana Street
Huntington Park 90255

Southland Drain Oil and Vacuum
Service
13219 Goller Avenue
Norwalk 90650

Standard Oil Co. of California
225 Bush Street
San Francisco

Steverson Bros.
18062 Gothard
Huntington Beach 92648

The Superior Oil Co.
State Highway 43 & 7th Standard Rd.
Bakersfield 93302

Union Oil Co. of California
9654 S. Santa Fe Srpings Road
Santa Fe Springs 90670

United Pumping Service
6059 1/2 E. Olympic
Los Angeles 90022

John E. Walden
21700 Dial-Way Ct.
Corona

W. L. Watson & Son
16741 Saticoy Street
Van Nuys 91406

Western Disposal Co.
1017 Gladstone
Azusa 91702

ILLINOIS

Clearing Disposal, Inc.
5245 W. 38 Cicero
Chicago

General Refuse Disposal Co.
11641 S. Ridgeland
Worth

Kankakee Industrial Disposal
P. O. Box 742
Kankee 60901

INDIANA

Calumet Waste Systems
7337 W. 15th Ave.
Gary

Home Sanitation Service
5607 W. 101st Ave.
Crown Point

Independent Waste Systems, Inc.
1020 Kennedy
Schererville

Midwest Disposal Co.
6514 E. 109th Ave.
Crown Point

Mr. Frank, Inc.
201 W. 155th St.
So. Holland

Superior Waste Systems, Inc.
1046 Sample
South Bend

LOUISIANA

B & M Trucking
P. O. Box 51957
Lafayette

Browning Ferris Industries
7850 Plank Road
Baton Rouge

Groendyke Transport
1907 St. Bernard Hwy.
Meraux

Gulf Coast Pre-Mix Trucking,
Inc.
P. O. Box 51271 O. C. S.
Lafayette

Matlack, Inc.
Mason Ave.
Baton Rouge Terminal

Merichem Co.
P. O. Box 61529
Houston
(Convent Area)

MICHIGAN

A. A. F. O. Disposal, Inc.
14491 Ronnie
Livonia

Fairall Trucking
18472 Allen Rd.
So. Gate

Kramer Waste Material Co.
9588 Greeley
Detroit

M. E. Trucking Co.
14740 Plymouth Rd.
Detroit

S. C. A. Services, Inc.
2151 Livernois
Troy

NEW JERSEY

Falesto Bros.
200 Merseles St.
Jersey City

Interstate Waste & Removal
208 Patterson Ave.
Trenton

Tri-County Disposal Service
Hiway 130
Robbinsville

NEW MEXICO

American Waste Removal
Jemez Dam Rd.
Bernalillo
(Albuquerque Area)

OHIO

Commercial Oil Services
3600 Cedar Point
Oregon
(Toledo Area)

Ohio Sanitation Systems, Inc.
Buckeye Road
Lima

OKLAHOMA

Atco Fuels, Inc.
5200 S. Harvard
Tulsa

B & C Tank Truck, Inc.
RFD 2, Box 532
Stroud

Bacon Transport
Box 1134
Ardmore

Banner, Inc.
Box 3306
Tulsa

Bigheart Crude Oil Corp.
Box 376
Tulsa

Buster's Transports, Inc.
202 E. Market
Box 1681
Enid

Lola M. Cain (Mrs.) Executrix
Of Estate of A. O. Cain
RFD 1,
Ponca City

Chaparral Transports, Inc.
505 S. Hayes
Enid

Kenneth F. Fackrell
421 "K" S. W.
Ardmore

Groendyke Transport, Inc.
2510 Rock Island Ave.
Enid

Roger K. Graves
Box 1125
Ardmore

Jack Haskin
Cushing Hot Oil Treating Co.
Box 769
Cushing

H. L. Henderson
Henderson's Oil Field Service
Stroud

Victor Hiebert
2201 Meadowbrook
Enid

J-B Tank Trucks, Inc.
Enid

Ray I. Jones Service Co.
2710 S. Van Buren
Enid

John R. Martin
John R. Martin Tank Truck
Service
Box 383
Cushing

Tom Mason & Carl Mason
Midway Tank Trucks
Stroud

Vernon Richardson
Richardson Tank Trucks
Cushing

Rogers Trucking, Inc.
Box 573
Stroud

Tom Scherer, Inc.
5200 S. Harvard
Tulsa

Target Service Co., Inc.
2409 Sherwood Dr.
Enid

Transportation Services, Inc.
Box 6703
Tulsa

A. F. Wass
Lumber and Hardware, Inc.
12 W. Main
Cyril

PENNSYLVANIA

Ace Service Corp.
123 Wilder St.
Philadelphia

Amo Pollution Services
2743 Nobletown Rd.
Pittsburg

Charles Crumbley
2334 N. 24
Philadelphia

Kasper Bros.
4579 Torresdale Ave.
Philadelphia

A. Marininn's Sons, Inc.
3301 Tulip St.
Philadelphia

Tri-County Hauling
1777 Calcon Hook Rd.
Sharon Hill

TEXAS

Bio Ecology Systems, Inc.
4100 E. Jefferson
Dallas

Coastal Vacuum Tank Service
8412 Hansen
Houston

Force Oil & Vacuum Company
5707 Polk
Houston

Gulf & Metallurgical Co.
Hiway 519
Box 2130
Texas City

Liberty Waste Disposal Co
Box 3370
Baytown

Merichem Co.
P. O. Box 61529
Houston
(Baytown Area)

Rollins Environmental Services
Deer Park

Texas Industrial Disposal, Inc.
920 S. Lamar
Dallas

Western Refuse of Texas, Inc.
129 North Shaver
Houston

UTAH

Ace Disposal Co.
945 Hyland Lake Dr.

Reliable Waste Systems
1550 West
North Temple

(Salt Lake Area)

WASHINGTON

Airo Services, Inc.
2103 112th St.
Tacoma

Liquid Waste Disposal Co.
1318 4th
Seattle

Resource Recovery Corp.
5501 Airport Way
Seattle

APPENDIX O

POTENTIAL FOR INTER-MEDIA TRANSFER OF SOME COMMONLY OCCURRING METALS

Throughout this report the environmental consequences of waste disposal have been treated as an indeterminate. Generally, the variety of environmental situations that might arise are too complex to enable simple categorization. In particular, the various mechanisms of inter-media transfer are unknown, except in specific well-investigated situations. However, it is useful to have some generalized picture of the fate of important trace metals. The following notes are a preliminary evaluation.

APPENDIX O

POTENTIAL FOR INTER-MEDIA TRANSFER OF SOME COMMONLY OCCURRING METALS

Element	Mobility	Biological Response	Soil Phase	Water Phase
Arsenic	Generally low. Limited by co-precipitation as arsenic trioxide (AsO_3^{-3}) with limonite and as $FeAsO_4$ (scorodite). In iron deficient environments, arsenic becomes more mobile.	Plants apparently tend to solubilize arsen ic to a certain extent, since arsenic is somewhat enriched in the humus horizon of soils. Arsenic content of coal ash is extremely high, evidencing concentration in organic matter as an important phenomena in the geological past.	Present in limonite and in organic matter to a minor degree.	
Beryllium	Probably low. Limited by the insolubility of beryl in weathering.	Beryllium in plants approximates that occurring in soil.		
Cadmium	Cadmium closely associated with zinc in weathering except during the oxidation of zinc sulfide. Here the secondary cadmium sulfide tends to remain behind after the zinc sulfide has been solubilized by oxidation.			

Element	Mobility	Biological Response	Soil Phase	Water Phase
Chromium	Generally low except under conditions of high pH and Eh where the mobile chromate ion is stable.		Present in limonite	Present as ionic chromate (CrO_4 at high pH and Eh)
Cobalt	Probably moderately high, limited in early stages by co-precipitation with limonite and MnO_2.	Important in animal nutrition.	Present in limonite and MnO_2.	Probably as cobalt Co^{++}.
Copper	High when pH is below 5.5, low at neutral to alkaline pH. Mobility is limited primarily by pH and to a lesser extent by co-precipitation with limonite, and absorption on organic matter and clay minerals.	Copper is one of the important plant nutrients. Where copper content of soils is below 10 ppm, deficiency symptoms may develop in vegetation. Higher concentrations of copper in soils may be toxic to plants dependent on soil pH.	Present in limonite, MnO_2, and organic matter.	Present as ionic copper (CU^+ and Cu^{++}), in floating organisms and soluble organic matter.
Fluorine	Not particularly mobile, limited by the abundance of phosphate.	Fluorine is not known to exist in plants. In animal nutrition, fluoride plays a part in the structure of teeth and bones.	Present in secondary phosphates.	Present as ionic fluorine.

Element	Mobility	Biological Response	Soil Phase	Water Phase
Lead	Generally low because of its precipitation with organic matter and limonite, but probably higher in chlorite (semi-arid) environments.	Generally toxic to vegetation when present in ionic form.	Enrichments of more than 1,000 ppm of lead in organic rich soil under certain conditions has been reported. Lead is enriched in the ferruginous horizon of lateritic soils.	Probably as ionic lead Pb^{++}.
Mercury	Probably low in water, but apparently quite high in the vapor phase.			
Molybdenum	Varies from moderate to high. Limited (1) by the rate of solution of primary MoS_2, (2) by sorption on limonite to form ferrimolybdite at pH's from 2.5 to 7 and to a lesser extent on clay minerals at pH 2 to 4, and (3) by precipitation in carbonate rich environments. Under all other conditions, mobility of molybdenum is independent of pH variations.		Present in limonite or clay minerals.	Present as MoO_4 ion, and the undissociated $MoO_2:SO_4$.

Element	Mobility	Biological Response	Soil Phase	Water Phase
Nickel	Moderately high, but limited by co-precipitation with limonite and hydrolysis above pH 6.5		Probably limonite and nickeliferous silicates.	Probably ionic nickel Ni^{++}.
Selenium	Selenium is highly mobile under oxidizing, alkaline conditions, and apparently highly immobile under reducing and neutral to acidic conditions. Mobility is limited by the stability fields of soluble SeO_4^{--} ion and the insoluble selenium and selenites.	The biological cycle of selenium is outstanding in that certain plants will take up and concentrate extremely large quantities of selenium from selenium rich soils. Selenium in plants acts as a severe poison for most grazing animals.	Limonite and ferric selenite.	Ionic SeO_4^{--}.
Vanadium	Probably very low. Limited by reaction and precipitation with organic matter.		Present in clay minerals and vanadates.	Probably as ionic VO_4^{3-}.
Zinc	Moderately high but limited by organic activity and co-precipitation with limonite.	Essential nutrient for almost all plants. Algae absorb a large part of the zinc dissolved in water. Zinc is also toxic to most forms of plants if it is present in amounts exceeding certain limits.	Sorbed on limonite and in lattice positions of clay minerals.	Variable distribution between floating organisms, soluble organic matter and ionic zinc Zn^{++}.

APPENDIX P

CONCENTRATION LEVELS OF HAZARDOUS COMPONENTS OF REFINERY WASYE STREAMS

The attached tabulation presents analytical data that were obtained from the sampling and analysis program performed by the contractor. From these data the concentration ranges used in the data extrapolations in Section 4.6 were derived.

CRUDE TANK BOTTOMS
All numbers in mg/kg except where noted

Refinery Code	A2	A1	B4	C2								
Refinery Category	III	II	IV	II								
Parameter	-											
Phenols	15.	21.	16.5	6.1								
Cyanide	< 0.13	< 0.025	< 0.1	0.8								
Selenium (Se)	< 4.0	< 2.0	≤ 1.0	1.0								
Arsenic (As)	53.0	33.0	9.2	5.8								
Mercury (Hg)	0.07	0.82	1.53	0.14								
Beryllium (Be)	< 0.32	< 0.2	≤ 0.13	0.25								
Vanadium (V)	12.8	22.0	62.0	5.0								
Chromium (Cr)	1.9	36.0	75.0	2.8								
Cobalt (Co)	3.8	22.0	37.0	7.5								
Nickel (Ni)	12.8	125.0	14.0	18.3								
Copper (Cu)	55.8	194.0	75.0	18.5								
Zinc (Zn)	141.0	425.0	150.0	22.8								
Silver (Ag)	< 0.3	0.12	1.3	0.25								
Cadmium (Cd)	0.32	0.42	0.3	0.25								
Lead (Pb)	10.9	25.0	338.	12.8								
Molybdenum (Mo)	< 2.5	10.0	95.0	2.5								
Ammonium Salts (as NH_4)	2.0	-	-									
Benz-A-Pyrene (PNA)	< 0.3	0.6	< 2.0	0.2								
Oil	83.6 %	39.8 %	55.0 %	21.0 %								

LEADED TANK BOTTOMS

All numbers in mg/kg except where noted

Refinery Code	C4	B2										
Refinery Category	IV	IV										
Parameter												
Phenols	250.0	2.1										
Cyanide	< 0.08	<0.1										
Selenium (Se)	10.8	3.1										
Arsenic (As)	63.0	525.0										
Mercury (Hg)	0.19	0.94										
Beryllium (Be)	<0.25	<0.25										
Vanadium (V)	9.8	<10.0										
Chromium (Cr)	13.7	9.0										
Cobalt (Co)	71.0	26.5										
Nickel (Ni)	392.0	235.0										
Copper (Cu)	172.0	110.0										
Zinc (Zn)	1183.0	17,000.0										
Silver (Ag)	1.7	< 0.5										
Cadmium (Cd)	8.1	4.5										
Lead (Pb)	1420.0	158.0										
Molybdenum (Mo)	118.0	<5.0										
Ammonium Salts (as NH_4)	-	-										
Benz-A-Pyrene (PNA)	0.4	<0.2										
Oil	18.9 %	21.0 %										

NON-LEADED TANK BOTTOMS

All numbers in mg/kg except where noted

Refinery Code	C4	A2									
Refinery Category	IV	III									
Parameter											
Phenols	1.7	1.8									
Cyanide	14.7	< 0.05									
Selenium (Se)	1.5	22.4									
Arsenic (As)	< 0.9	< 0.5									
Mercury (Hg)	0.41	0.44									
Beryllium (Be)	< 0.25	0.49									
Vanadium (V)	9.1	34.6									
Chromium (Cr)	12.7	13.1									
Cobalt (Co)	5.9	8.2									
Nickel (Ni)	41.0	12.4									
Copper (Cu)	164.0	6.2									
Zinc (Zn)	541.0	29.7									
Silver (Ag)	0.7	0.49									
Cadmium (Cd)	0.4	0.25									
Lead (Pb)	37.3	12.1									
Molybdenum (Mo)	18.2	< 2.5									
Ammonium Salts (as NH_4)	-	0.2									
Benz-A-Pyrene (PNA)	0.9	0.3									
Oil	83.2 %	45.1 %									

API SEPARATOR SLUDGE

All numbers in mg/kg except where noted

Refinery Code	A	A	B3	A3	B1	C4	A4	C3	B2	B5	B4	A6
Refinery Category	IV	IV	II	III	II	IV	IV	IV	IV	III	IV	III
Parameter												
Phenols	156.7	65.8	15.2	9.1	32.0	5.4	11.9	3.8	6.5	112.0	10.3	15.6
Cyanide	< 0.006	< 0.01	0.3	51.4	0.15	< 0.09	< 0.1	12.6	2.0	< 0.1	< 0.1	< 0.1
Selenium (Se)	< 1.0	4.7	< 2.0	4.3	7.6	< 0.5	< 1.0	< 1.0	< 1.0	1.0	< 1.0	1.0
Arsenic (As)	3.3	5.1	3.7	32.0	9.4	< 1.0	9.0	15.	5.4	7.0	8.0	1.0
Mercury (Hg)	1.57	1.15	0.45	0.32	0.15	0.3	0.36	2.9	0.05	6.2	3.21	0.04
Beryllium (Be)	< 0.2	< 0.2	< 0.2	0.24	< 0.2	< 0.12	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Vanadium (V)	6.2	12.	7.5	48.5	28.0	40.0	5.0	45.0	15.0	< 10.0	< 10.0	< 10.0
Chromium (Cr)	130.0	950.0	102.0	6790.0	750.0	110.0	70.0	285.0	445.0	280.0	225.0	< 1.0
Cobalt (Co)	2.2	7.8	3.6	26.2	1.0	23.0	1.3	10.5	< 1.0	13.0	14.5	< 1.0
Nickel (Ni)	22.3	37.5	16.3	150.4	13.8	25.0	< 2.5	34.0	7.5	10.0	30.0	6.0
Copper (Cu)	8.9	21.2	14.0	514.0	77.0	14.5	6.0	550.0	29.0	23.0	16.0	2.5
Zinc (Zn)	95.0	475.0	70.0	6596.0	388.0	140.0	25.0	1050.0	255.0	340.0	340.0	31.0
Silver (Ag)	0.4	0.6	0.2	0.97	0.2	3.0	0.25	1.0	0.5	1.5	< 0.5	< 0.5
Cadmium (Cd)	0.21	0.34	0.28	< 0.24	0.29	3.0	< 0.25	0.5	0.5	2.0	0.5	1.0
Lead (Pb)	25.0	26.0	9.0	60.6	5.0	25.0	40.0	32.5	10.0	< 2.5	1290.0	83.0
Molybdenum (Mo)	2.5	7.5	5.0	19.4	3.8	< 5.0	< 2.5	5.0	5.0	10.0	60.0	< 5.0
Ammonium Salts (as NH_4)	4.9	< 0.5	< 1.0	--	30.0	2.0	8.4	--	24.0	14.0	7.0	6.0
Benz-A-Pyrene (PNA)	< 0.3	< 0.3	< 0.3	3.7	< 0.3	1.1	< 0.2	2.3	< 0.2	< 1.8	4.5	< 0.5
Oil	22.8 %	26.8 %	45.1 %	14.5 %	12.7 %	59.8 %	3.3 %	22.3 %	18.0 %	34.4 %	19.6 %	43.0 %

Note: Sample from refinery A3 is a dewatered cake.

NEUTRALIZED HF ALKYLATION SLUDGE
All numbers in mg/kg except where noted

Refinery Code	A2	A3										
Refinery Category	III	III										
Parameter												
Phenols	3.2	14.6										
Cyanide	45.9	0.21										
Selenium (Se)	<1.0	14.0										
Arsenic (As)	4.5	<0.5										
Mercury (Hg)	0.05	0.09										
Beryllium (Be)	<0.12	0.13										
Vanadium (V)	5.0	<2.5										
Chromium (Cr)	0.75	5.0										
Cobalt (Co)	<0.25	0.7										
Nickel (Ni)	103.0	7.4										
Copper (Cu)	26.0	2.5										
Zinc (Zn)	9.5	8.6										
Silver (Ag)	0.25	0.12										
Cadmium (Cd)	0.12	<0.12										
Lead (Pb)	4.5	9.6										
Molybdenum (Mo)	<2.5	<2.5										
Ammonium Salts (as NH_4)	<0.2	<0.2										
Benz-A-Pyrene (PNA)	-	<0.2										
Oil	6.7 %	7.1 %										
Fluoride, F	76,600.	20,000										

KEROSENE FILTER CLAYS

All numbers in mg/kg except where noted

Refinery Code	A	A2	C4	C3	B[illegible]							
Refinery Category	IV	III	IV	IV	IV							
Parameter												
Phenols	2.6	25.2	2.0	6.4	<0.5							
Cyanide	≤ 0.025	< 0.05	<0.07	≤ 0.1	0.22							
Selenium (Se)	<1.0	26.1	9.6	2.1	<1.0							
Arsenic (As)	2.2	14.0	<0.9	1.4	<0.5							
Mercury (Hg)	≤ 0.04	0.05	<0.04	0.33	0.04							
Beryllium (Be)	0.2	0.35	<0.25	0.50	<0.25							
Vanadium (V)	42.0	35.0	13.2	65.0	<5.0							
Chromium (Cr)	2.88	25.8	0.9	45.0	1.3							
Cobalt (Co)	0.62	2.3	0.4	5.0	1.3							
Nickel (Ni)	< 2.5	15.0	<4.0	22.0	<2.5							
Copper (Cu)	11.4	9875.0	0.4	8.0	0.5							
Zinc (Zn)	35.0	25.0	6.6	115.0	0.5							
Silver (Ag)	0.7	0.5	<0.2	1.0	<0.13							
Cadmium (Cd)	0.19	0.25	0.4	1.5	< 0.25							
Lead (Pb)	12.0	4.25	8.3	< 2.5	2.3							
Molybdenum (Mo)	<1.2	<2.5	8.8	< 5.0	< 2.5							
Ammonium Salts (as NH_4)	-	-	<1	-	2.0							
Benz-A-Pyrene (PNA)	-	1.7	1.8	0.2	< 0.2							
Oil	.7 %	3.5 %	5.6 %	39.8 %	3.9 %							

ONCE-THROUGH COOLING WATER SLUDGE

All numbers in mg/kg except where noted

Refinery Code	A5	C3	B4									
Refinery Category	II	IV	IV									
Parameter												
Phenols	2.0	2.0	2.1									
Cyanide	0.74	0.11	< 0.1									
Selenium (Se)	10.4	1.6	< 1.0									
Arsenic (As)	< 1.0	18.0	5.4									
Mercury (Hg)	0.51	0.42	1.34									
Beryllium (Be)	0.24	0.63	< 0.13									
Vanadium (V)	39.0	57.0	15.0									
Chromium (Cr)	16.6	63.0	103.0									
Cobalt (Co)	11.2	6.3	5.5									
Nickel (Ni)	39.0	20.5	35.0									
Copper (Cu)	57.4	153.0	180.0									
Zinc (Zn)	93.0	233.0	125.0									
Silver (Ag)	.24	1.3	0.5									
Cadmium (Cd)	<0.24	1.0	< 0.3									
Lead (Pb)	17.2	57.0	138.0									
Molybdenum (Mo)	<0.5	2.5	33.0									
Ammonium Salts (as NH_4)	6.0	13.0	< 1.0									
Benz-A-Pyrene (PNA)	< 0.3	1.8	< 0.4									
Oil	0.24%	0.43%	17.0%									

DISSOLVED AIR FLOTATION (DAF) FLOAT

All numbers in mg/kg except where noted

Refinery Code	C4	B4	A2	A4	C2							
Refinery Category	IV	IV	III	IV	II							
Parameter												
Phenols	6.5	210.0	33.0	3.0	3.6							
Cyanide	0.28	<0.1	0.78	1.1	<0.1							
Selenium (Se)	4.2	2.8	<1.0	<1.0	2.0							
Arsenic (As)	<1.0	2.6	10.5	2.0	<0.5							
Mercury (Hg)	0.25	0.89	0.27	0.46	0.07							
Beryllium (Be)	<0.12	<0.25	0.25	<0.25	<0.25							
Vanadium (V)	<15.0	<10.0	<5.0	<5.0	<5.0							
Chromium (Cr)	117.5	140.0	260.0	233.0	28.0							
Cobalt (Co)	67.5	2.0	3.3	<1.3	2.0							
Nickel (Ni)	15.0	5.0	<2.5	<2.5	<2.5							
Copper (Cu)	6.5	21.0	21.3	7.0	<0.5							
Zinc (Zn)	85.0	395.0	1825.0	62.0	10.0							
Silver (Ag)	2.8	<0.5	0.25	<0.13	0.5							
Cadmium (Cd)	0.5	<0.5	<0.25	0.50	<0.25							
Lead (Pb)	7.5	1250.0	2.3	2.8	183.0							
Molybdenum (Mo)	<5.0	<5.0	<2.5	2.5	<2.5							
Ammonium Salts (as NH_4)	210.0	9.0	8.7	8.5	18.0							
Benz-A-Pyrene (PNA)	1.75	<0.4	<0.2	<0.2	<0.2							
Oil	12.5 %	16.9 %	14.4 %	5.9 %	2.4 %							

SLOP OIL EMULSION SOLIDS

All numbers in mg/kg except where noted

Refinery Code	A1	C4	A	B2	B5	A6	A2	A4	C2			
Refinery Category	II	IV	IV	IV	IV	III	III	IV	II			
Parameter												
Phenols	7.9	9.6	127.1	7.5	68.0	15.0	68.0	33.6	5.7			
Cyanide	52.5	< 0.09	< 0.004	0.15	<0.1	<0.1	< 0.1	0.4	1.6			
Selenium (Se)	<2.0	8.8	< 2.4	1.4	1.6	<1.0	1.0	<1.0	4.2			
Arsenic (As)	2.9	2.5	3.5	18.5	8.6	2.8	7.4	7.8	10.5			
Mercury (Hg)	0.14	5.67	0.88	4.4	12.25	<0.05	0.37	0.28	0.59			
Beryllium (Be)	<0.2	0.22	0.38	< 0.25	< 0.25	<0.25	<0.5	<0.25	<0.25			
Vanadium (V)	<1.2	75.0	11.0	65.0	15.0	35.0	<10.0	5.0	25.0			
Chromium (Cr)	278.0	600.0	444.0	1750.0	525.0	<1.0	435.0	389.0	825.0			
Cobalt (Co)	1.9	82.5	4.2	22.5	34.5	<1.0	6.0	5.0	10.0			
Nickel (Ni)	33.8	145.0	35.0	160.0	14.0	50.0	7.5	60.0	30.8			
Copper (Cu)	9.0	111.5	15.9	420.0	360.0	8.5	98.0	31.5	48.0			
Zinc (Zn)	125.0	656.0	325.0	2725.0	60.0	80.0	235.0	250.0	650.0			
Silver (Ag)	0.4	20.1	0.2	< 0.5	1.5	0.5	< 0.25	<0.13	0.25			
Cadmium (Cd)	0.19	0.5	0.30	1.5	2.0	<0.5	<0.5	< 0.25	<0.25			
Lead (Pb)	19.0	28.1	31.0	275.0	< 2.5	290.0	17.0	10.8	580.0			
Molybdenum (Mo)	1.2	10.0	3.8	20.0	5.0	<5.0	5.0	<2.5	5.0			
Ammonium Salts (as NH_4)	2.5	-	< 9.6	-	8.0	10.0	18.0	44.0	1.5			
Benz-A-Pyrene (PNA)	<0.3	< 0.2	< 0.3	<1.8	<1.5	<1.8	<0.2	<0.2	<0.2			
Oil	34.8 %	59.4 %	27.9 %	48.0 %	62.0 %	63.2 %	62.0%	35.0%	36.0 %			

Sample from B2 is cake from a rotary filter.

SPENT LIME FROM BOILER FEEDWATER TREATMENT

All numbers in mg/kg except where noted

Refinery Code	A	A3	A4	C4	C1	B5	B4					
Refinery Category	IV	III	IV	IV	III	IV	IV					
Parameter												
Phenols	--	1.8	2.9	1.3	2.3	3.6	<0.5					
Cyanide	<0.002	<0.04	1.28	<0.09	<0.1	<0.1	<0.1					
Selenium (Se)	<1.0	<1.0	12.2	<1.0	<1.0	<1.0	<1.0					
Arsenic (As)	0.05	<0.5	<0.5	2.3	1.0	<1.0	2.6					
Mercury (Hg)	<0.04	<0.04	<0.04	2.73	0.04	0.17	0.5					
Beryllium (Be)	<0.1	<0.12	<0.12	<0.12	<0.13	<0.13	<0.2					
Vanadium (V)	<0.7	<2.5	<2.5	31.6	<5.0	<5.0	<5.0					
Chromium (Cr)	0.07	5.3	<0.25	27.9	<0.5	5.8	2.2					
Cobalt (Co)	0.18	1.0	<0.25	<0.2	<0.5	<0.5	1.3					
Nickel (Ni)	1.0	22.5	2.5	19.4	<1.3	<1.3	12.5					
Copper (Cu)	0.22	3.8	1.8	63.2	2.0	9.5	6.3					
Zinc (Zn)	2.0	27.5	6.8	121.0	3.8	15.0	70.0					
Silver (Ag)	0.05	0.25	0.5	0.7	0.5	0.5	0.5					
Cadmium (Cd)	0.03	<0.12	<0.12	0.1	0.3	<0.3	<0.25					
Lead (Pb)	<0.1	7.3	<0.5	6.8	2.5	3.8	5.0					
Molybdenum (Mo)	<0.25	<2.5	<2.5	<5.0	<2.5	<2.5	<2.5					
Ammonium Salts (as NH_4)	<1.0	4.0	5.0	<1.0	0.6	<0.5	<1.5					
Benz-A-Pyrene (PNA)	-	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2					
Oil	0.49 %	0.25%	0.49 %	0.06 %	0.32 %	0.04 %	0.34 %					

COOLING TOWER SLUDGE

All numbers in mg/kg except where noted

Refinery Code	A	B1	C4	C3								
Refinery Category	IV	II	IV	IV								
Parameter												
Phenols	7.0	4.1	2.8	0.6								
Cyanide	< 0.005	< 0.03	17.2	0.21								
Selenium (Se)	2.4	< 2.0	<1.0	<1.0								
Arsenic (As)	2.3	0.7	21.0	14.0								
Mercury (Hg)	0.1	< 0.04	0.09	3.35								
Beryllium (Be)	<0.1	0.2	< 0.12	<0.13								
Vanadium (V)	8.0	<1.2	35.0	7.5								
Chromium (Cr)	765.0	181.0	1750.0	343.0								
Cobalt (Co)	1.2	0.38	7.0	1.3								
Nickel (Ni)	10.5	< 2.5	50.0	3.0								
Copper (Cu)	49.0	13.0	50.0	363.0								
Zinc (Zn)	650.0	118.0	1100.0	700.0								
Silver (Ag)	0.05	<0.1	1.6	0.5								
Cadmium (Cd)	0.29	0.06	0.6	0.3								
Lead (Pb)	68.0	1.2	89.0	7.5								
Molybdenum (Mo)	1.0	1.2	2.5	<2.5								
Ammonium Salts (as NH_4)	<0.7	2.5	10.0	14.0								
Benz-A-Pyrene (PNA)	<0.3	<0.3	0.8	<0.5								
Oil	0.16 %	0.72 %	0.07 %	4.0 %								

EXCHANGER BUNDLE CLEANING SLUDGE

All numbers in mg/kg except where noted

Refinery Code	A	A6										
Refinery Category	IV	III										
Parameter												
Phenols	18.5	8.0										
Cyanide	<0.004	3.3										
Selenium (Se)	52.0	2.4										
Arsenic (As)	10.2	11.0										
Mercury (Hg)	3.6	0.14										
Beryllium (Be)	0.34	< 0.5										
Vanadium (V)	0.7	50.0										
Chromium (Cr)	311.0	310.0										
Cobalt (Co)	3.0	< 2.0										
Nickel (Ni)	61.0	170.0										
Copper (Cu)	67.0	75.0										
Zinc (Zn)	297.0	91.0										
Silver (Ag)	< 0.07	<1.0										
Cadmium (Cd)	1.5	1.0										
Lead (Pb)	155.0	< 5.0										
Molybdenum (Mo)	12.0	<10.0										
Ammonium Salts (as NH_4)	11.0	5.0										
Benz-A-Pyrene (~~PNA~~	0.7	3.6										
Oil	8.3%	13.0%										

WASTE BIO SLUDGE

All numbers in mg/kg except where noted

Refinery Code	B1	A1	B5	B4	A6							
Refinery Category	II	II	IV	IV	III							
Parameter												
Phenols	10.2	5.5	4.5	3.6	1.7							
Cyanide	5.8	19.5	<0.1	<0.1	<0.1							
Selenium (Se)	5.4	3.8	<1.0	<1.0	<1.0							
Arsenic (As)	4.6	6.0	2.0	3.8	1.0							
Mercury (Hg)	0.18	0.54	1.28	0.1	<0.04							
Beryllium (Be)	<0.2	<0.2	<0.13	<0.13	<0.13							
Vanadium (V)	<1.2	5.0	5.0	<5.0	<5.0							
Chromium (Cr)	331.0	300.0	475.0	40.0	<0.5							
Cobalt (Co)	0.2	1.4	0.5	<0.5	<0.5							
Nickel (Ni)	<2.5	11.3	2.5	<2.5	<1.3							
Copper (Cu)	10.2	11.5	9.5	3.0	1.5							
Zinc (Zn)	122.0	225.0	153.0	35.0	3.3							
Silver (Ag)	0.1	0.4	0.5	0.3	0.3							
Cadmium (Cd)	0.16	0.54	0.3	0.3	0.3							
Lead (Pb)	1.2	17.0	5.0	1.3	12.5							
Molybdenum (Mo)	2.5	2.5	<2.5	2.5	<2.5							
Ammonium Salts (as NH_4)	6.5	30.0	15.0	27.0	21.0							
Benz-A-Pyrene (PNA)	<0.3	<0.3	<0.3	<0.2	<0.5							
Oil	0.53%	0.28%	0.45%	0.04%	0.01%							

STORM WATER SILT

All numbers in mg/kg except where noted

Refinery Code	C4	A1										
Refinery Category	IV	II										
Parameter												
Phenols	6.3	8.6										
Cyanide	.34	3.1										
Selenium (Se)	1.1	2.2										
Arsenic (As)	1.0	10.0										
Mercury (Hg)	0.23	0.36										
Beryllium (Be)	≤0.12	<0.25										
Vanadium (V)	25.0	112.0										
Chromium (Cr)	32.5	675.0										
Cobalt (Co)	11.3	11.0										
Nickel (Ni)	30.0	140.0										
Copper (Cu)	14.8	41.8										
Zinc (Zn)	60.0	400.0										
Silver (Ag)	0.5	0.5										
Cadmium (Cd)	≤0.1	0.42										
Lead (Pb)	20.5	86.0										
Molybdenum (Mo)	6.3	7.5										
Ammonium Salts (as NH_4)	1.0	-										
Benz-A-Pyrene (PNA)	<0.3	2.5										
Oil	5.5 %	2.2 %										

FCC CATALYST FINES

All numbers in mg/kg except where noted

Refinery Code	B1	A5	A3	A2	A4	A	C4	C3	B2	C1	B4
Refinery Category	II	II	III	III	IV	IV	IV	IV	IV	III	IV
Parameter											
Phenols	1.4	1.2	72.0	3.2	4.1	0.3	1.8	6.4	2.1	0.7	10.2
Cyanide	0.16	<0.1		0.1	1.44	0.092	0.62	<0.1	0.13	0.27	<0.1
Selenium (Se)	<2.0	19.1	1.1	6.7	<1.0	<1.0	<1.0	<1.0	1.6	1.4	<1.0
Arsenic (As)	2.4	<0.5	<0.5	<0.5	<0.5	1.0	0.9	3.2	3.8	2.0	4.0
Mercury (Hg)	<0.04	0.1	0.16	0.04	0.07	<0.04	<0.04	0.06	<0.04	<0.04	<0.04
Beryllium (Be)	0.2	1.25	1.25	0.84	0.43	0.88	1.4	0.25	<0.25	<0.25	0.5
Vanadium (V)	940.0	768.0	240.0	74.4	82.5	95.0	1724.0	475.0	105.0	1,150	180.0
Chromium (Cr)	41.0	17.3	82.5	36.0	12.3	84.0	71.0	95.0	29.0	85.0	190.0
Cobalt (Co)	6.5	16.8	4.0	9.8	0.25	4.4	37.0	7.8	6.5	6.56	27.5
Nickel (Ni)	586.0	648.0	117.5	120.0	47.5	153.0	241.0	270.0	190.0	1000.0	275.0
Copper (Cu)	4.1	28.3	17.3	8.9	7.0	11.6	336.0	62.0	17.5	11.5	29.5
Zinc (Zn)	19.0	79.2	77.5	21.6	25.0	50.0	133.6	170.0	27.0	27.0	110.0
Silver (Ag)	1.2	2.0	2.1	2.4	1.6	0.5	2.2	1.8	1.0	0.5	3.0
Cadmium (Cd)	0.12	<0.12	<0.12	<0.12	<0.12	0.14	<0.1	<0.3	<0.5	0.5	<0.5
Lead (Pb)	17.0	25.2	195.0	19.0	50.0	55.0	94.8	59.0	39.0	10.0	77.0
Molybdenum (Mo)	12.0	6.0	6.3	5.0	5.0	1.2	21.6	12.5	<5.0	10.0	15.0
Ammonium Salts (as NH_4)	-	-	-	-	-	-	-	-	<1.0	-	-
Benz-A-Pyrene (PNA)	<0.3	<0.2	1.5	<0.2	<0.2	-	1.0	<0.5	<0.4	0.6	0.4
Oil	0.01 %	0.25 %	0.05 %	0.06 %	0.10 %	4.1 %	0.21 %	0.03 %	1.3 %	3.2 %	0.81 %

μσ1435

COKE FINES

All numbers in mg/kg except where noted

Refinery Code	A	C1	C1*	A6	B2
Refinery Category	IV	III	III	III	IV
Parameter					
Phenols	0.4	2.0	2.7	2.0	2.5
Cyanide	< 0.025	<0.1	< 0.10	<0.1	<0.1
Selenium (Se)	<1.0	<1.0	<1.0	1.6	<1.0
Arsenic (As)	5.4	< 2.0	<2.0	2.0	10.8
Mercury (Hg)	<0.04	0.06	0.2	< 0.1	0.04
Beryllium (Be)	<0.25	<0.5	0.5	<0.3	0.25
Vanadium (V)	400.0	800.0	430.0	455.0	3500.0
Chromium (Cr)	7.5	< 2.0	< 2.0	< 2.0	6.0
Cobalt (Co)	9.2	3.0	4.0	< 2.0	5.0
Nickel (Ni)	575.0	800.0	580.0	350.0	2200.0
Copper (Cu)	3.5	4.0	4.0	5.0	5.0
Zinc (Zn)	15.0	11.0	14.0	20. 0	<2.0
Silver (Ag)	0.25	<1.0	<1.0	<1.0	3.0
Cadmium (Cd)	< 0.15	1.0	1.0	2.0	<1.0
Lead (Pb)	29.0	< 5.0	10.0	24.0	13.0
Molybdenum (Mo)	2.5	<10.0	<10.0	<10.0	<10.0
Ammonium Salts (as NH_4)	-	-	0.7	-	-
Benz-A-Pyrene (PNA)	-	<0.2	<0.2	<0.5	<0.2
Oil	0.12 %	< 0.1 %	<0.1 %	1.34 %	NIL %

C1* = coke chunks not fines

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